NUREG-1575, Rev. 1
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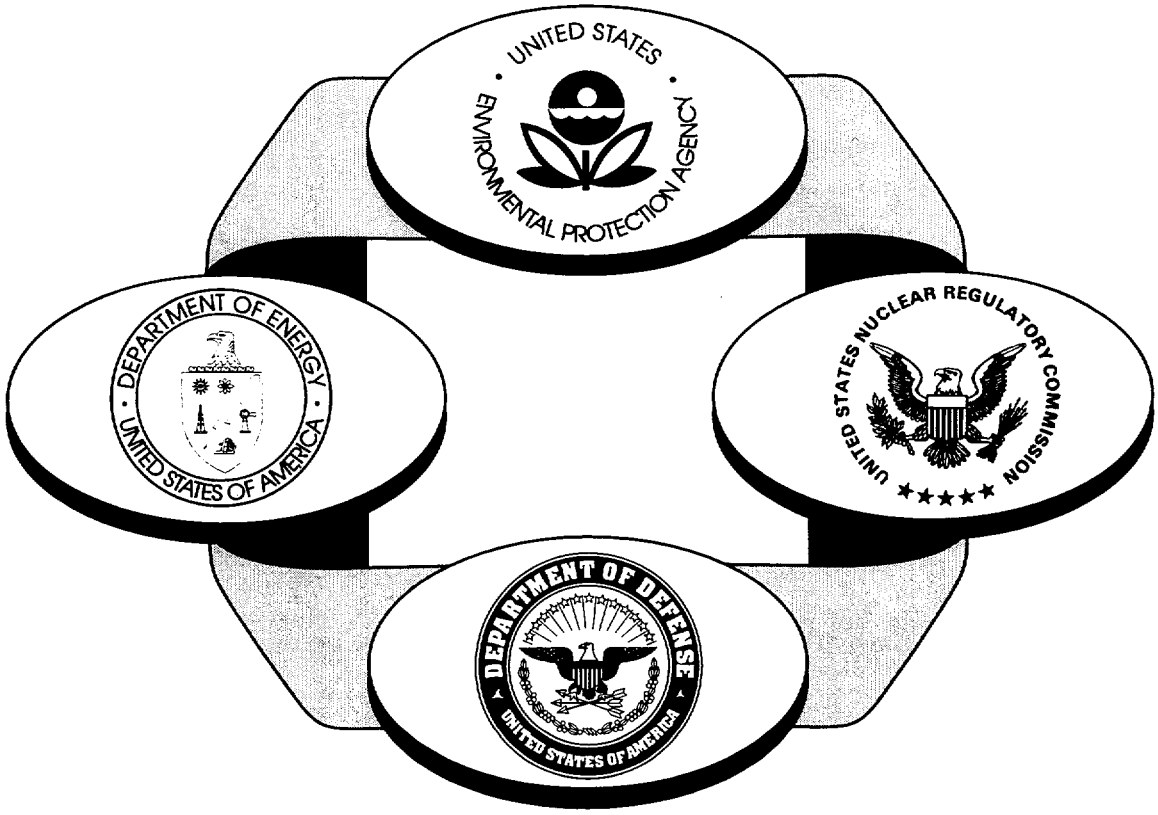
MULTI-AGENCY RADIATION SURVEY AND SITE INVESTIGATION MANUAL (MARSSIM)



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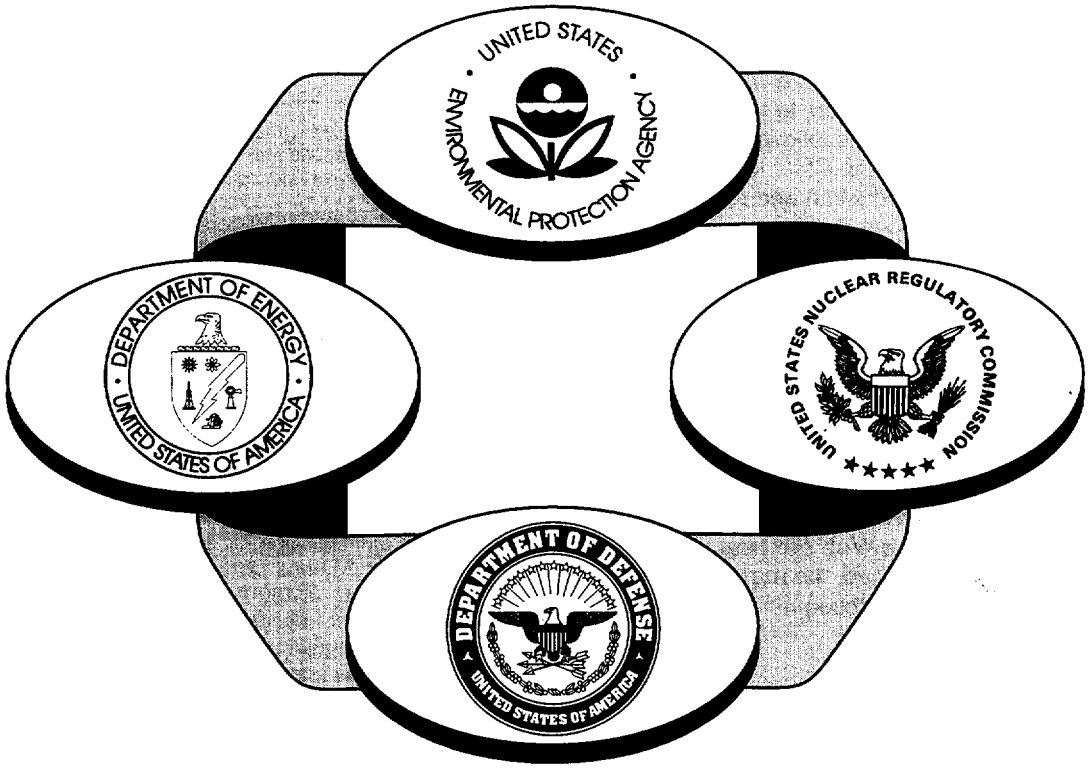

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Submit written comments arising from the review or use of MARSSIM to EITHER the U.S. Environmental Protection Agency, ATTN: Air and Radiation Docket, Mail Stop 6102, Air Docket No. A-96-44, First Floor Waterside Mall (geographic address at 401 M Street, SW.), mailing address 1200 Pennsylvania Ave., NW., Washington D.C. 20460-2001 or the Chief, Rules and Directives Branch, Division of Administrative Services, U.S. Nuclear Regulatory Commission, Washington DC 20555-0001. As appropriate, revised pages of MARSSIM will be posted on the Internet at: http://www.epa.gov/radiation/marssim.

ABSTRACT

The MARSSIM provides information on planning, conducting, evaluating, and documenting building surface and surface soil final status radiological surveys for demonstrating compliance with dose or risk-based regulations or standards. The MARSSIM is a multi-agency consensus document that was developed collaboratively by four Federal agencies having authority and control over radioactive materials: Department of Defense (DOD), Department of Energy (DOE), Environmental Protection Agency (EPA), and Nuclear Regulatory Commission (NRC). The MARSSIM's objective is to describe a consistent approach for planning, performing, and assessing building surface and surface soil final status surveys to meet established dose or risk-based release criteria, while at the same time encouraging an effective use of resources.

DISCLAIMER

This manual was prepared by four agencies of the United States Government. Neither the United States Government nor any agency or branch thereof, or any of their employees, makes any warranty, expressed or implied, or assumes any legal liability of responsibility for any third party's use, or the results of such use, of any information, apparatus, product, or process disclosed in this manual, or represents that its use by such third party would not infringe on privately owned rights.

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CDR Colleen F. Petullo, U.S. Public Health Service, EPA, Chair

EPA: Mark Doehnert
Anthony Wolbarst, Ph.D.
H. Benjamin Hull
Sam Keith, CHP*
Jon Richards

DOE: Hal Peterson, CHP
Kenneth Duvall
Andrew Wallo III

NRC: Robert A. Meck, Ph.D.
Anthony Huffert
George E. Powers, Ph.D.
David Fauver, CHP
Cheryl Trottier

DOD: David Alberth, CHP (Army)
CDR Lino Fragoso, Ph.D. (Navy)
Lt. Col. Donald Jordan (Air Force)
Capt. Kevin Martilla (Air Force)
Julie Coleman (Air Force)

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EPA: Scott Hay (S. Cohen & Associates, Inc.)
Todd Peterson, Ph.D. (S. Cohen & Associates, Inc.)
Harry Chmelynski, Ph.D. (S. Cohen & Associates, Inc.)
Ralph Kenning, CHP (S. Cohen & Associates, Inc.)

NRC: Eric Abelquist, CHP (Oak Ridge Institute of Science and Education)
James Berger (Auxier & Associates)
Carl Gogolak, Ph.D. (DOE/EML, under contract with NRC)

* Formerly with EPA National Air and Radiation Environmental Laboratory (NAREL). Currently with the Agency for Toxic Substances and Disease Registry (ATSDR).

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John Kirk Williams (Oak Ridge National Laboratory)
Romance Carrier (Oak Ridge National Laboratory)

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Chair

James E. Watson, Jr., Ph.D., University of North Carolina at Chapel Hill

Members

William Bair, Ph.D., (Retired), Battelle Pacific Northwest Laboratory
Stephen L. Brown, Ph.D., R2C2 (Risks of Radiation and Chemical Compounds)
June Fabryka-Martin, Ph.D., Los Alamos National Laboratory
Thomas F. Gesell, Ph.D., Idaho State University
F. Owen Hoffman, Ph.D., SENES Oak Ridge, Inc.
Janet Johnson, Ph.D., Shepherd Miller, Inc.
Bernd Kahn, Ph.D., Georgia Institute of Technology
Ellen Mangione, M.D., Colorado Department of Health
Paul J. Merges, Ph.D., New York State Department of Environmental Conservation

SAB Consultants

Michael E. Ginevan, Ph.D., M.E. Ginevan & Associates
David G. Hoel, Ph.D., University of South Carolina
David E. McCurdy, Ph.D., Yankee Atomic Electric Company
Frank L. Parker, Ph.D., Vanderbilt University [Liaison from Environmental Management Advisory Board, U.S. Department of Energy]

Science Advisory Board Staff

K. Jack Kooyoomjian, Ph.D., Designated Federal Official, EPA
Mrs. Diana L. Pozun, Staff Secretary, EPA

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K. Allison	A.T. Kearney
L. Abramson	NRC
R. Abu-Eid	NRC
W. Beck	Oak Ridge Institute of Science and Education
A. Boerner	Oak Ridge Institute of Science and Education
Lt. E. Bonano	Air Force
M. Boyd	EPA
J. Buckley	NRC
B. Burns	Army
W. Cottrell	Oak Ridge National Laboratory
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M. Eagle	EPA
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L. Hendricks	Nuclear Environmental Services
K. Hogan	EPA
R. Hutchinson	National Institute of Standards and Technology
G. Jablonowski	EPA
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H. Larson	NRC
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J. Lux	Kerr-McGee Corporation
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H. Mukhoty	EPA
A.J. Nardi	Westinghouse
D. Ottlieg	Westinghouse Hanford Company
V. Patania	Oak Ridge National Laboratory
C.L. Pittiglio	NRC
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P. Reed	NRC
R. Rodriguez	Oak Ridge National Laboratory
N. Rohnig	
R. Schroeder	Army
C. Simmons	Kilpatrick & Cody
E. Stamataky	EPA
R. Story	Foster Wheeler
E. Temple	EPA
D. Thomas	Air Force
S. Walker	EPA
P. White	EPA
R. Wilhelm	EPA

ABBREVIATIONS

AEA	Atomic Energy Act
AEC	Atomic Energy Commission
AFI	Air Force Instructions
ALARA	as low as reasonably achievable
AMC	Army Material Command
ANSI	American National Standards Institute
AR	Army Regulations
ASTM	American Society of Testing and Materials
ATSDR	Agency for Toxic Substances and Disease Registry
CAA	Clean Air Act
Capt.	Captain (Air Force)
CAPT	Captain (Navy)
CDR	Commander
CEDE	committed effective dose equivalent
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Information System
CFR	Code of Federal Regulations
CHP	Certified Health Physicist
CPM	counts per minute
DARA	Department of the Army Radioactive Material Authorization
DCF	dose conversion factor
DCGL	derived concentration guideline level
$DCGL_{EMC}$	DCGL for small areas of elevated activity, used with the EMC
$DCGL_{W}$	DCGL for average concentrations over a wide area, used with statistical tests
DEFT	Decision Error Feasibility Trials
DLC	Data Life Cycle
DOD	Department of Defense
DOE	Department of Energy
DOT	Department of Transportation
DQA	Data Quality Assessment
DQO	Data Quality Objectives
EERF	Eastern Environmental Radiation Facility
Ehf	human factors efficiency
EMC	elevated measurement comparison
EML	Environmental Measurements Laboratory
EMMI	Environmental Monitoring Methods Index
EPA	Environmental Protection Agency
EPIC	Environmental Photographic Interpretation Center
ERAMS	Environmental Radiation Ambient Monitoring System

ABBREVIATIONS

FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Maps
FRDS	Federal Reporting Data System
FSP	Field Sampling Plan
FWPCA	Federal Water Pollution Control Act
FUSRAP	Formerly Utilized Sites Remedial Action Program
GEMS	Geographical Exposure Modeling System
GM	Geiger-Mueller
GPS	global positioning system
GRIDS	Geographic Resources Information Data System
GWSI	Ground Water Site Inventory
H_0	null hypothesis
H_a	alternative hypothesis
HSA	Historical Site Assessment
HSWA	Hazardous and Solid Waste Amendments
ISI	Information System Inventory
L_C	critical level
L_D	detection limit
LBGR	lower bound of the gray region
LCDR	Lieutenant Commander
LLRWPA	Low Level Radioactive Waste Policy Act as Amended
LT	Lieutenant
MARLAP	Multi-Agency Radiation Laboratory Analytical Protocols (Manual)
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MCA	multichannel analyzer
MDC	minimum detectable concentration
MDCR	minimum detectable count rate
MED	Manhattan Engineering District
NARM	naturally occurring or accelerator produced radioactive material
NCAPS	National Corrective Action Prioritization System
NCRP	National Council on Radiation Protection and Measurements
NCP	National Contingency Plan
NIST	National Institute of Standards and Technology
NORM	naturally occurring radioactive material
NPDC	National Planning Data Corporation

ABBREVIATIONS

NPDES	National Pollutant Discharge Elimination System
NRC	Nuclear Regulatory Commission
NWPA	Nuclear Waste Policy Act
NWWA	National Water Well Association
ODES	Ocean Data Evaluation System
ORNL	Oak Ridge National Laboratory
ORISE	Oak Ridge Institute for Science and Education
PERALS	photon electron rejecting alpha liquid scintillator
PIC	pressurized ionization chamber
QA	quality assurance
QAPP	Quality Assurance Project Plan
QC	quality control
QMP	Quality Management Plan
RASP	Radiological Affairs Support Program
RAGS/HHEM	Risk Assessment Guidance for Superfund/Human Health Evaluation Manual
RC	release criterion
RCRA	Resource Conservation and Recovery Act
RCRIS	Resource Conservation and Recovery Information System
RI/FS	Remedial Investigation/Feasibility Study
ROD	Record of Decision
RODS	Records of Decision System
RSSI	Radiation Survey and Site Investigation
SARA	Superfund Amendments and Reauthorization Act
SAP	Sampling and Analysis Plan
SDWA	Safe Drinking Water Act
SFMP	Surplus Facilities Management Program
SOP	Standard Operating Procedures
STORET	Storage and Retrieval of U.S. Waterways Parametric Data
TEDE	total effective dose equivalent
TLD	thermoluminescence dosimeter
TRU	transuranic
TSCA	Toxic Substances Control Act

ABBREVIATIONS

UMTRCA	Uranium Mill Tailings Radiation Control Act
USGS	United States Geological Survey
USPHS	United States Public Health Service
USRADS	Ultrasonic Ranging and Data System
WATSTORE	National Water Data Storage and Retrieval System
WL	working level
WRS	Wilcoxon rank sum
WSR	Wilcoxon signed ranks
WT	Wilcoxon test

CONVERSION FACTORS

To Convert From	To	Multiply By	To Convert From	To	Multiply By
acre	hectare	0.405	meter (m)	inch	39.4
	sq. meter (m^2)	4,050		mile	0.000621
	sq. feet (ft^2)	43,600	sq. meter (m^2)	acre	0.000247
becquerel (Bq)	curie (Ci)	$2.7x10^{-11}$		hectare	0.0001
	dps	1		sq. feet (ft^2)	10.8
	pCi	27		sq. mile	$3.86x10^{-7}$
Bq/kg	pCi/g	0.027	m^3	liter	1,000
Bq/m^2	dpm/100 cm^2	0.60	mrem	mSv	0.01
Bq/m^3	Bq/L	0.001	mrem/y	mSv/y	0.01
	pCi/L	0.027	mSv	mrem	100
centimeter (cm)	inch	0.394	mSv/y	mrem/y	100
Ci	Bq	$3.70x10^{10}$	ounce (oz)	liter (L)	0.0296
	pCi	$1x10^{12}$	pCi	Bq	0.037
				dpm	2.22
dps	dpm	60	pCi/g	Bq/kg	37
	pCi	27	pCi/L	Bq/m^3	37
dpm	dps	0.0167	rad	Gy	0.01
	pCi	0.451	rem	mrem	1,000
gray (Gy)	rad	100		mSv	10
hectare	acre	2.47		Sv	0.01
liter (L)	cm^3	1000	seivert (Sv)	mrem	100,000
	m^3	0.001		mSv	1,000
	ounce (fluid)	33.8		rem	100

AUGUST 2000 ERRATA AND ADDENDA

In response to comments received on the December 1997 Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM), minor modifications were made to individual pages. Modifications to the manual that correct errors are listed as errata, while modifications made to clarify guidance or provide additional information are referred to as addenda. The pages affected by these modifications are listed here. A complete list of comments and resolutions is available on the MARSSIM web site at:

http://www.epa.gov/radiation/marssim/

Pages Modified to Correct Errata

v, xv, xxvii, Roadmap-4, 1-3, 2-6, 2-11, 2-12, 4-33, 4-35, 4-36, 4-37, 4-38, 5-33, 6-4, 6-10, 6-23, 6-37, 7-20, 8-19, 9-3, 9-4, 9-7, Ref-3, Ref-4, A-2, A-5, A-7, A-11, A-14, A-19, E-2, H-7, H-8, H-10, H-12, H-14, H-16, H-32, I-30, N-2, N-6, N-8, N-11, N-13

Pages Modified to Provide Addenda

xiii, xxiii, xxviii, 5-30, 5-34, 7-8, C-20, C-21, D-23, I-5, L-2, L-3, L-4, L-5, L-8, , M-10

ROADMAP

Introduction to MARSSIM

The Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) provides detailed guidance for planning, implementing, and evaluating environmental and facility radiological surveys conducted to demonstrate compliance with a dose- or risk-based regulation. The MARSSIM guidance focuses on the demonstration of compliance during the final status survey following scoping, characterization, and any necessary remedial actions.

The process of planning the survey, implementing the survey plan, and assessing the survey results prior to making a decision is called the Data Life Cycle. MARSSIM Chapter 2 and Appendix D provide detailed guidance on developing appropriate survey designs using the Data Quality Objectives (DQO) Process to ensure that the survey results are of sufficient quality and quantity to support the final decision. The survey design process is described in MARSSIM Chapters 3, 4, and 5. Guidance on selecting appropriate measurement methods (*i.e.*, scan surveys, direct measurements, samples) and measurement systems (*i.e.*, detectors, instruments, analytical methods) is provided in MARSSIM Chapters 6 and 7 and Appendix H. Data Quality Assessment (DQA) is the process of assessing the survey results, determining that the quality of the data satisfies the objectives of the survey, and interpreting the survey results as they apply to the decision being made. The DQA process is described in MARSSIM Chapter 2 and Appendix E and is applied in MARSSIM Chapter 8. Quality Assurance and Quality Control (QA/QC) procedures are developed and recorded in survey planning documents, such as a Quality Assurance Project Plan (QAPP) which is described in MARSSIM Chapter 9.

MARSSIM does not provide guidance for translating the release criterion into derived concentration guideline levels (DCGLs). MARSSIM discusses contamination of surface soil and building surfaces in detail. If other media (*e.g.*, ground water, surface water, subsurface soil, equipment, vicinity properties) are potentially contaminated at the time of the final status survey, modifications to the MARSSIM survey design guidance and examples may be required.

The Goal of the Roadmap

The goal of the roadmap is to present a summary of the major steps in the design, implementation, and assessment of a final status survey and to identify where guidance on these steps is located in MARSSIM. A brief description of each step is included in the roadmap along with references to the sections of MARSSIM that provide more detailed guidance.

This roadmap provides the user with basic guidance from MARSSIM combined with "rules of thumb" (indicated by ☞) for performing compliance demonstration surveys. The roadmap is not designed to be a stand-alone document, but to be used as a quick reference to MARSSIM for

users already familiar with the process of planning and performing surveys. Roadmap users will also find flow charts summarizing the major steps in the Radiation Survey and Site Investigation Process, combined with references to sections in MARSSIM where detailed guidance may be found. In addition, the roadmap serves as an overview and example for applying MARSSIM guidance at sites with radioactive contamination of surface soil and building surfaces. The roadmap assumes a working knowledge of MARSSIM terminology. If such knowledge is lacking, the user may refer to Section 2.2 of MARSSIM for definitions of key terms. In addition, a complete set of definitions is provided in the Glossary.

Data Life Cycle

Compliance demonstration is simply a decision as to whether or not a survey unit meets the release criterion. For most sites, this decision is supported by statistical tests based on the results of one or more surveys. The initial assumption used in MARSSIM is that each survey unit is contaminated above the release criterion until proven otherwise. The surveys are designed to provide the information needed to reject this initial assumption. MARSSIM recommends using the Data Life Cycle as a framework for planning, implementing, and evaluating survey results prior to making a decision. Figure 1 summarizes the major activities associated with each phase of the Data Life Cycle.

Planning Stage

The survey design is developed and documented using the Data Quality Objectives (DQO) Process (Section 2.3.1, Appendix D). The DQOs for the project are established and preliminary surveys (*e.g.*, scoping, characterization) are performed to provide information necessary to design the final status survey for compliance demonstration. The DQOs for the project are re-evaluated for each of the preliminary surveys. The preliminary surveys may provide information for purposes other than compliance demonstration that are not discussed in MARSSIM. For example, a characterization survey may provide information to support evaluation of remedial alternatives. In addition, any of the preliminary surveys may be designed to demonstrate compliance with the release criterion as one of the survey objectives. These alternate survey designs are developed based on site-specific considerations (Section 2.6). The planning phase of the Data Life Cycle produces a final status survey design that is used for demonstrating compliance with the release criterion. This design is recorded in planning documents, such as a Quality Assurance Project Plan (QAPP) described in Section 9.2.

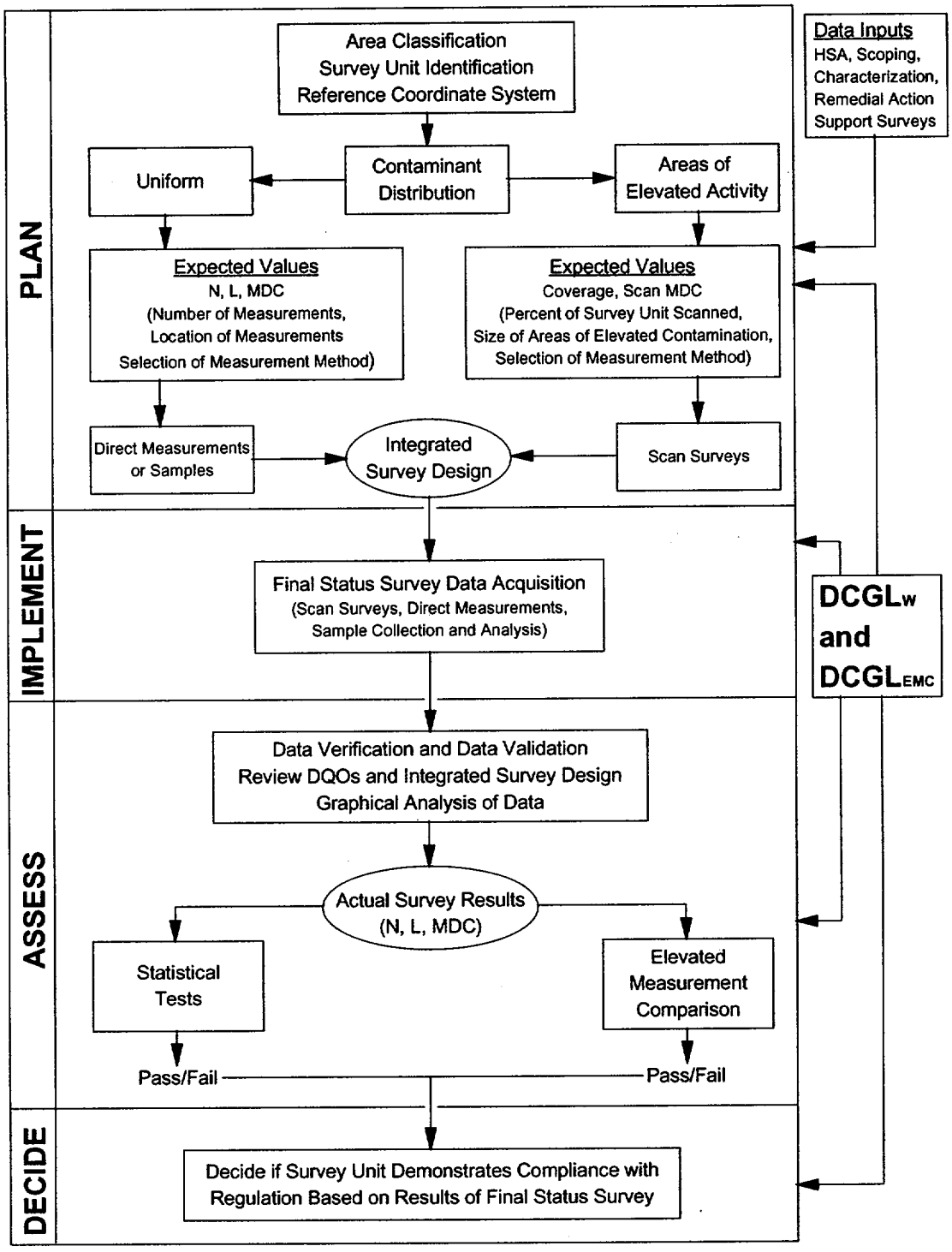

Figure 1 The Data Life Cycle Applied to a Final Status Survey

A minimum amount of information is needed from the preliminary surveys to develop an effective final status survey design. This includes

- Sufficient information to justify classification and specification of boundaries for survey units (the default is Class 1 which results in the highest level of survey effort)
- An estimate of the variability of the contaminant concentration in the survey unit (σ_s) and the reference area (σ_r) if necessary

After the preliminary surveys are completed, the final status survey design can be developed. Figure 2 presents the major steps in the development of a survey design that integrates scanning surveys with direct measurements and sampling. Most of the steps are easy to understand and references to appropriate sections of MARSSIM are included in the flowchart. Several of these steps are important enough to justify additional discussion in this guide. These steps are

- Classify Areas by Contamination Potential
- Group/Separate Areas into Survey Units
- Determine Number of Data Points
- Select Instrumentation
- Develop an Integrated Survey Design

Classify Areas by Contamination Potential (Section 4.4)

Classification is a critical step in survey design because it determines the level of survey effort based on the potential for contamination. Overestimating the potential for contamination results in an unnecessary increase in the level of survey effort. Underestimating the potential for contamination greatly increases the probability of failing to demonstrate compliance based on the survey results. There are two key decisions made when classifying areas: 1) is the average activity in the area likely to exceed the $DCGL_W$, and 2) is the contamination present in small areas of elevated activity or is the contamination distributed relatively homogeneously across the area. Each of these decisions is considered separately when designing the survey and then combined into an integrated survey design. Class 1 areas, prior to remediation, are impacted areas with concentrations of residual radioactivity that exceed the $DCGL_W$. Class 2 areas are impacted areas where concentrations of residual activity that exceed the $DCGL_W$ are not expected. Class 3 areas are impacted areas that have a low probability of containing areas with residual radioactivity. The information obtained from the preliminary surveys is crucial for classifying areas (see Figure 2.4).

☞ Area classification considers both the level of contamination relative to the $DCGL_W$ and the distribution of the contamination. The contamination may be uniformly distributed or present as small areas of elevated activity.

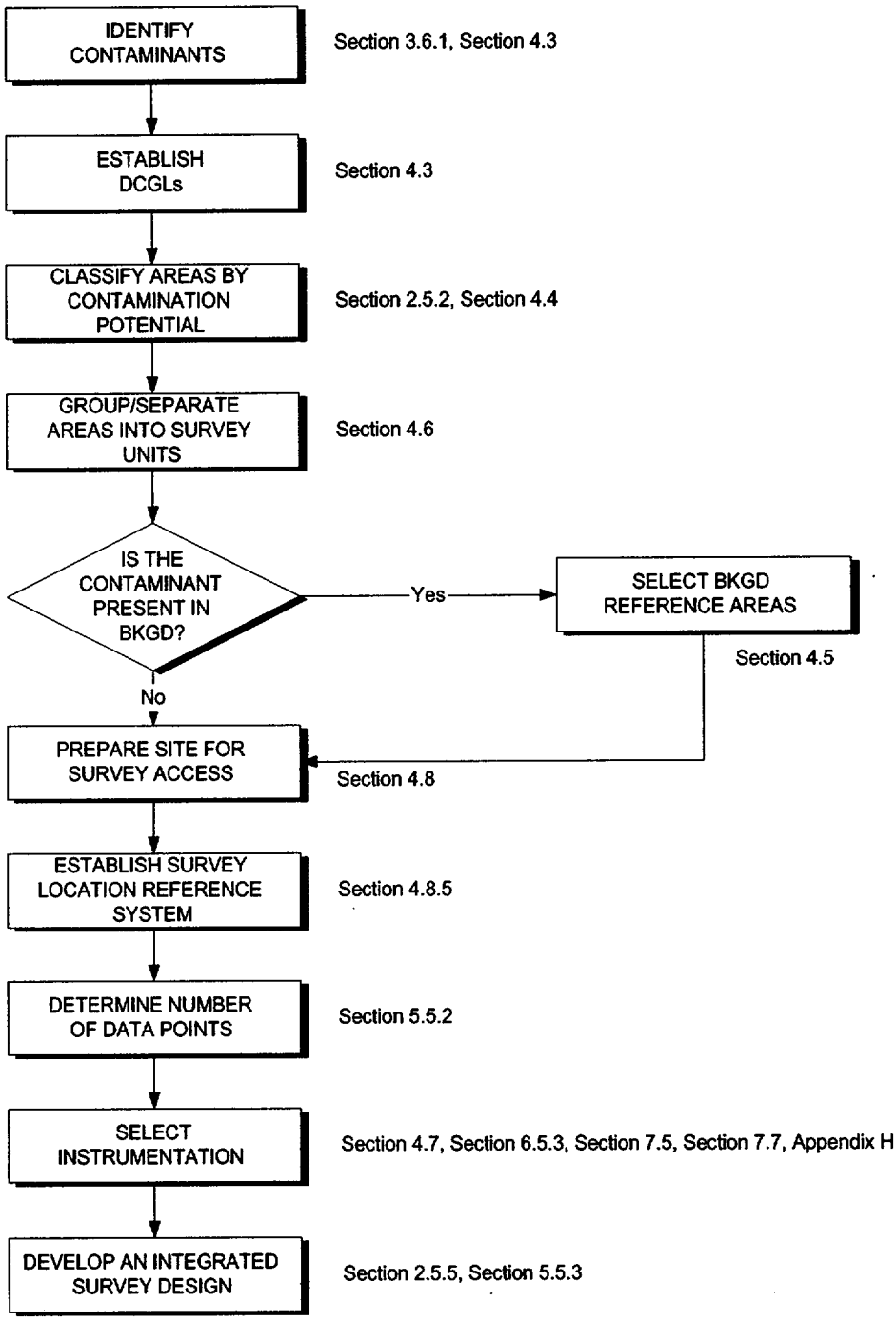

Figure 2 Flow Diagram for Designing a Final Status Survey

Group/Separate Areas into Survey Units (Section 4.6)

Survey units are limited in size based on classification, exposure pathway modeling assumptions, and site-specific conditions. Table 1 provides suggested survey unit areas based on area classification. The rationale for selecting a larger survey unit area should be developed using the DQO Process and fully documented.

Table 1 Suggested Survey Unit Areas

Classification	Suggested Area
Class 1	
Structures	up to 100 m^2
Land Areas	up to 2,000 m^2
Class 2	
Structures	100 to 1,000 m^2
Land Areas	2,000 to 10,000 m^2
Class 3	
Structures	no limit
Land Areas	no limit

☞ Survey unit areas should be consistent with exposure pathway modeling assumptions used to develop DCGLs.

Determine Number of Data Points (Section 5.5.2)

The number of data points is determined based on the selection of a statistical test, which in turn is based on whether or not the contaminant is present in background. Figure 3 presents a flow chart for determining the number of data points.

The first step in determining the number of data points is to specify the acceptable decision error rates, α and β. Decision error rates are site-specific and selected using the DQO Process. Changes in the values of α and β may result from successive iterations of the DQO Process.

☞ Values for α and β are site-specific and selected using the DQO Process.

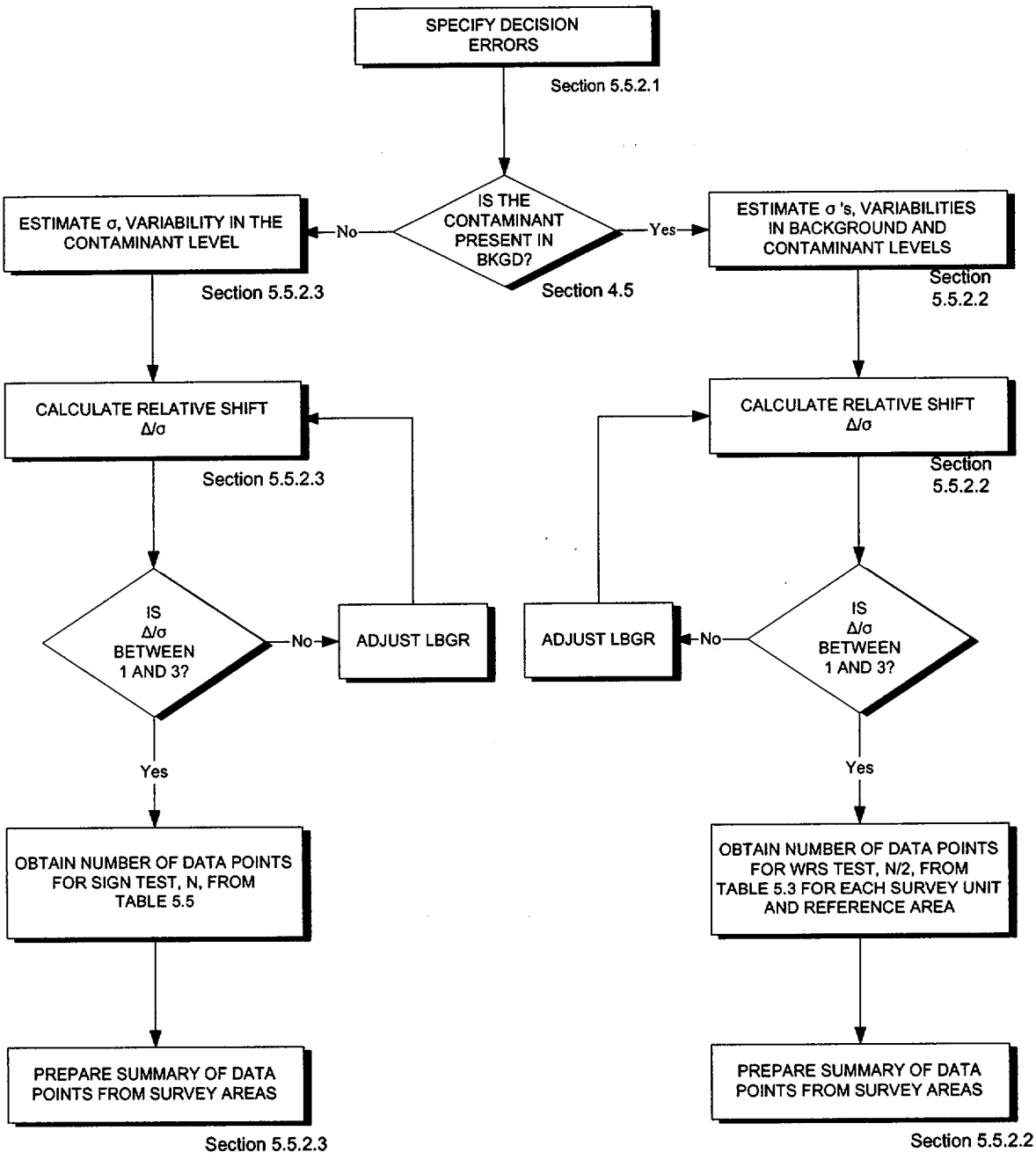

Figure 3 Flow Diagram for Determining the Number of Data Points

The next step, after determining whether or not the contaminant is present in background, is to estimate the variability of the contaminant concentration, σ. The standard deviation of the contaminant concentration determined from the preliminary survey results should provide an appropriate estimate of σ. If the contaminant is present in background, the variability in the survey unit (σ_s) and the variability in the reference area (σ_r) should both be estimated. The larger of the two values should be selected for determining the number of data points. Underestimating σ can underestimate the number of measurements needed to demonstrate compliance with the regulation, which increases the probability the survey unit will fail the statistical test. Overestimating σ can result in collecting more data than is necessary to demonstrate compliance.

☞ It is better to overestimate values of σ_s and σ_r.

☞ When σ_s and σ_r are different, select the larger of the two values.

The third step is to calculate the relative shift, Δ/σ. The variability of the contaminant concentration, σ, was determined in the previous step. The shift, Δ, is equal to the width of the gray region. The upper bound of the gray region is defined as the $DCGL_W$. The lower bound of the gray region (LBGR) is a site-specific parameter, adjusted to provide a value for Δ/σ between one and three. Δ/σ can be adjusted using the following steps:

- Initially select LBGR to equal one half the $DCGL_W$. This means Δ ($DCGL_W$ - LBGR) also equals one half the $DCGL_W$. Calculate Δ/σ.
- If Δ/σ is between one and three, obtain the appropriate number of data points from Table 5.3 or Table 5.5.
- If Δ/σ is less than one, select a lower value for LBGR. Continue to select lower values for LBGR until Δ/σ is greater than or equal to one, or until LBGR equals zero.
- If Δ/σ is greater than three, select a higher value for LBGR. Continue to select higher values for LBGR until Δ/σ is less than or equal to three.

Alternatively, Δ/σ can be adjusted by solving the following equation and calculating Δ/σ:

$$LBGR = DCGL_W - \sigma$$

If LBGR is less than zero, Δ/σ can be calculated as $DCGL_W/\sigma$.

☞ Adjust the LBGR to provide a value for Δ/σ between one and three.

The final step in determining the number of data points is to obtain the appropriate value from Table 5.3 or Table 5.5. Table 5.3 provides the number of data points for each survey unit and each reference area when the contaminant is present in background (N/2). Table 5.5 provides the number of data points for each survey unit when the contaminant is not present in background (N).

Select Instrumentation (Section 4.7, Section 6.5.3, Section 7.5, Section 7.7, Appendix H)

Instrumentation or measurement techniques should be selected based on detection sensitivity to provide technically defensible results that meet the objectives of the survey. Because of the uncertainty associated with interpreting scanning results, the detection sensitivity of the selected instruments should be as far below the DCGL as possible. For direct measurements and sample analyses, minimum detectable concentrations (MDCs) less than 10% of the DCGL are preferable while MDCs up to 50% of the DCGL are acceptable.

☞ Estimates of the MDC that minimize potential decision errors should be used for planning surveys.

Develop an Integrated Survey Design (Section 5.5.3)

The integrated survey design combines scanning surveys with direct measurements and sampling. The level of survey effort is determined by the potential for contamination as indicated by the survey unit classification. This is illustrated in Figure 4. Class 3 survey units receive judgmental scanning and randomly located measurements. Class 2 survey units receive scanning over a portion of the survey unit based on the potential for contamination combined with direct measurements and sampling performed on a systematic grid. Class 1 survey units receive scanning over 100% of the survey unit combined with direct measurements and sampling performed on a systematic grid. The grid spacing is adjusted to account for the scan MDC (Section 5.5.2.4).

Table 2 provides a summary of the recommended survey coverage for structures and land areas. Modifications to the example survey designs may be required to account for other contaminated media (*e.g.*, ground water, subsurface soil).

Implementation Phase

The objectives outlined in the QAPP are incorporated into Standard Operating Procedures (SOPs). The final status survey design is carried out in accordance with the SOPs and the QAPP resulting in the generation of raw data. Chapter 6, Chapter 7, and Appendix H provide information on measurement techniques.

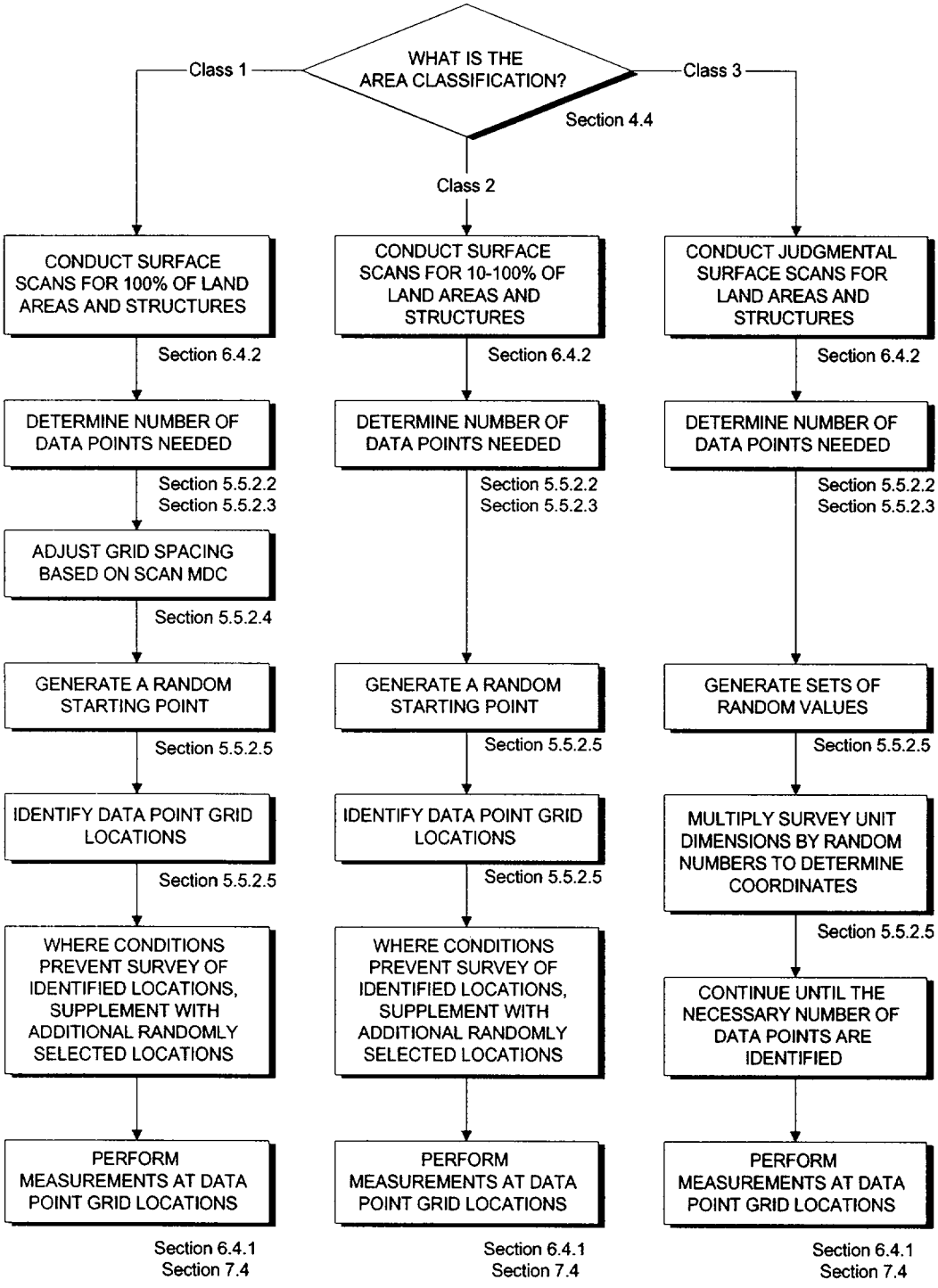

Figure 4 Flow Diagram for Developing an Integrated Survey Design

Table 2 Recommended Survey Coverage for Structures and Land Areas

Area Classification	Structures		Land Areas	
	Surface Scans	Surface Activity Measurements	Surface Scans	Surface Soil Measurements
Class 1	100%	Number of data points from statistical tests (Sections 5.5.2.2 and 5.5.2.3); additional direct measurements and samples may be necessary for small areas of elevated activity (Section 5.5.2.4)	100%	Number of data points from statistical tests (Sections 5.5.2.2 and 5.5.2.3); additional direct measurements and samples may be necessary for small areas of elevated activity (Section 5.5.2.4)
Class 2	10 to 100% (10 to 50% for upper walls and ceilings) Systematic and Judgmental	Number of data points from statistical tests (Sections 5.5.2.2 and 5.5.2.3)	10 to 100% Systematic and Judgmental	Number of data points from statistical tests (Sections 5.5.2.2 and 5.5.2.3)
Class 3	Judgmental	Number of data points from statistical tests (Sections 5.5.2.2 and 5.5.2.3)	Judgmental	Number of data points from statistical tests (Sections 5.5.2.2 and 5.5.2.3)

Assessment Phase

The assessment phase of the Data Life Cycle includes verification and validation of the survey results combined with an assessment of the quantity and quality of the data. As previously stated, both the average level of contamination in the survey unit and the distribution of the contamination within the survey unit are considered during area classification. For this reason, the assessment phase includes a graphical review of the data to provide a visual representation of the radionuclide distribution, an appropriate statistical test to demonstrate compliance for the average concentration of a uniformly distributed radionuclide, and the elevated measurement comparison (EMC) to demonstrate compliance for small areas of elevated activity.

The survey data are verified to ensure that SOPs specified in the survey design were followed and that the measurement systems were performed in accordance with the criteria specified in the QAPP (Section 9.3.1). The data are validated to ensure that the results support the objectives of the survey, as documented in the QAPP, or permit a determination that these objectives should be modified (Section 9.3.2). The Data Quality Assessment (DQA) process is then applied using

the verified and validated data to determine if the quality of the data satisfies the data user's needs. DQA is described in Appendix E and is applied in Chapter 8.

The first step in DQA is to review the DQOs and survey design to ensure that they are still applicable. For example, if the data suggest that a survey unit is misclassified, the DQOs and survey design would be modified for the new classification.

The next step is to conduct a preliminary data review to learn about the structure of the data and to identify patterns, relationships, or potential anomalies. This review should include calculating basic statistical quantities (*i.e.*, mean, standard deviation, median) and graphically presenting the data using at least a histogram and a posting plot. The results of the preliminary data review are also used to verify the assumptions of the tests. Some of the assumptions and possible methods for assessing them are summarized in Table 3. Information on diagnostic tests is provided in Section 8.2 and Appendix I.

Table 3 Methods for Checking the Assumptions of Statistical Tests

Assumption	Diagnostic
Spatial Independence	Posting Plot (Figure 8.1)
Symmetry	Histogram (Figure 8.2) Quantile Plot (Figure I.2)
Data Variance	Sample Standard Deviation (Section 8.2)
Power is Adequate	Retrospective Power Chart (Sign Test, Figure I.5) (WRS Test, Figure I.6)

The final step in interpreting the data is to draw conclusions from the data. Table 4 summarizes the statistical tests recommended in MARSSIM. Section 8.3 provides guidance on performing the Sign test when the contaminant is not present in background. Section 8.4 provides guidance on performing the Wilcoxon Rank Sum (WRS) test when the contaminant is present in background.

Table 4 Summary of Statistical Tests

Radionuclide not in background and radionuclide-specific measurements made:

Survey Result	Conclusion
All measurements less than $DCGL_W$	Survey unit meets release criterion
Average greater than $DCGL_W$	Survey unit does not meet release criterion
Any measurement greater than $DCGL_W$ and the average less than $DCGL_W$	Conduct Sign test and elevated measurement comparison

Radionuclide in background or radionuclide non-specific (gross) measurements made:

Survey Result	Conclusion
Difference between maximum survey unit measurement and minimum reference area measurements is less than $DCGL_W$	Survey unit meets release criterion
Difference of survey unit average and reference area average is greater than $DCGL_W$	Survey unit does not meet release criterion
Difference between any survey unit measurement and any reference area measurement greater than $DCGL_W$ and the difference of survey unit average and reference area average is less than $DCGL_W$	Conduct WRS test and elevated measurement comparison

Table 5 provides examples of final status survey investigation levels for each survey unit classification and type of measurement. For a Class 1 survey unit, measurements above the $DCGL_W$ are not necessarily unexpected. However, a measurement above the $DCGL_W$ at one of the discrete measurement locations might be considered unusual if it were much higher than all of the other discrete measurements. Thus, any discrete measurement that is above both the $DCGL_W$ and the statistical-based parameter for the measurements should be investigated further. Any measurement, either at a discrete location or from a scan, that is above the $DCGL_{EMC}$ should be flagged for further investigation.

In Class 2 or Class 3 areas, neither measurements above the $DCGL_W$ nor areas of elevated activity are expected. Any measurement at a discrete location exceeding the $DCGL_W$ in these areas should be flagged for further investigation. Because the survey design for Class 2 and Class 3 survey units is not driven by the EMC, the scanning MDC might exceed the $DCGL_W$. In this case, any indication of residual radioactivity during the scan would warrant further investigation.

Table 5 Summary of Investigation Levels

Survey Unit Classification	Flag Direct Measurement or Sample Result When:	Flag Scanning Measurement Result When:
Class 1	> $DCGL_{EMC}$ or > $DCGL_W$ and > a statistical-based parameter value	> $DCGL_{EMC}$
Class 2	> $DCGL_W$	> $DCGL_W$ or > MDC
Class 3	> fraction of $DCGL_W$	> $DCGL_W$ or > MDC

Because there is a low expectation for residual radioactivity in a Class 3 area, it may be prudent to investigate any measurement exceeding even a fraction of the $DCGL_W$. The level one chooses here depends on the site, the radionuclides of concern, and the measurement and scanning methods chosen. This level should be set using the DQO Process during the survey design phase of the Data Life Cycle. In some cases, the user may also decide to follow this procedure for Class 2 and even Class 1 survey units.

Both the measurements at discrete locations and the scans are subject to the EMC. The result of the EMC does not in itself lead to a conclusion as to whether the survey unit meets or exceeds the release criterion, but is a flag or trigger for further investigation. The investigation may involve taking further measurements in order to determine that the area and level of the elevated residual radioactivity are such that the resulting dose or risk meets the release criterion.[1] The investigation should also provide adequate assurance that there are no other undiscovered areas of elevated residual radioactivity in the survey unit that might result in a dose exceeding the release criterion. This could lead to a re-classification of all or part of a survey unit—that is, unless the results of the investigation indicate that reclassification is not necessary.

Decision Making Phase

A decision is made, in coordination with the responsible regulatory agency, based on the conclusions drawn from the assessment phase. The results of the EMC are used to demonstrate compliance with the dose- or risk-based regulation for small areas of elevated activity, while the nonparametric statistical tests are used to demonstrate that the average radionuclide concentration in the survey unit complies with the release criterion. The objective is to make technically defensible decisions with a specified level of confidence.

[1] Rather than, or in addition to, taking further measurements, the investigation may involve assessing the adequacy of the exposure pathway model used to obtain the DCGLs and area factors, and the consistency of the results obtained with the Historical Site Assessment and the scoping, characterization, and remedial action support surveys.

The EMC consists of comparing each measurement from the survey unit with the investigation levels in Table 5. The EMC is performed for measurements obtained from the systematic or random sample locations as well as locations flagged by scanning surveys. Any measurement from the survey unit that is equal to or greater than the investigation level indicates an area of relatively higher concentration and is investigated, regardless of the outcome of the nonparametric statistical tests.

> ☞ Any measurement from the survey unit that is equal to or greater than the investigation level indicates an area of relatively higher concentration and is investigated, regardless of the outcome of the nonparametric statistical tests.

The result of the Sign test or the WRS test is the decision to reject or not to reject the null hypothesis that the survey unit is contaminated above the $DCGL_W$. Provided that the results of any investigations triggered by the EMC have been resolved, a rejection of the null hypothesis leads to the decision that the survey unit meets the release criterion. If necessary, the amount of residual radioactivity in the survey unit can be estimated so that dose or risk calculations can be made. In most cases, the average concentration is the best estimate for the amount of residual radioactivity.

Summary

The roadmap presents a summary of the planning, implementation, assessment, and decision making phases for a final status survey and identifies where guidance on these phases is located in MARSSIM. Each step in the process is described briefly along with references to the sections of MARSSIM to which the user may refer for more detailed guidance. Flow charts are provided to summarize the major steps in the Radiation Survey and Site Investigation Process, again citing appropriate sections of MARSSIM. In addition to providing the user with basic guidance from MARSSIM, the roadmap also includes "rules of thumb" for performing compliance demonstration surveys.

1 INTRODUCTION

1.1 Purpose and Scope of MARSSIM

Radioactive materials have been produced, processed, used, and stored at thousands of sites throughout the United States. Many of these sites—ranging in size from Federal weapons-production facilities covering hundreds of square kilometers to the nuclear medicine departments of small hospitals—were at one time or are now radioactively contaminated.

The owners and managers of a number of sites would like to determine if these sites are contaminated, clean them up if contaminated, and release them for restricted use or for unrestricted public use. The Environmental Protection Agency (EPA), the Nuclear Regulatory Commission (NRC), and the Department of Energy (DOE) are responsible for the release of sites following cleanup. These responsibilities apply to facilities under the control of Federal agencies, such as the DOE and Department of Defense (DOD), and to sites licensed by the NRC and its Agreement States. Some States have responsibilities for similar sites under their control.

The Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) provides a nationally consistent consensus approach to conducting radiation surveys and investigations at potentially contaminated sites. This approach should be both scientifically rigorous and flexible enough to be applied to a diversity of site cleanup conditions. MARSSIM's title includes the term "survey" because it provides information on planning and conducting surveys, and includes the term "site investigation" because the process outlined in the manual allows one to begin by investigating any site (*i.e.*, by gathering data or information) that may involve radioactive contamination.

The decommissioning that follows remediation will normally require a demonstration to the responsible Federal or State agency that the cleanup effort was successful and that the release criterion (a specific regulatory limit) was met. In MARSSIM, this demonstration is given the name "final status survey." This manual assists site personnel or others in performing or assessing such a demonstration. (Generally, MARSSIM may serve to guide or monitor remediation efforts whether or not a release criterion is applied.)

As illustrated in Figure 1.1, the demonstration of compliance with respect to conducting surveys is comprised of three interrelated parts:

I. Translate: Translating the cleanup/release criterion (*e.g.*, mSv/y, mrem/y, specific risk) into a corresponding derived contaminant concentration level (*e.g.*, Bq/kg or pCi/g in soil) through the use of environmental pathway modeling.

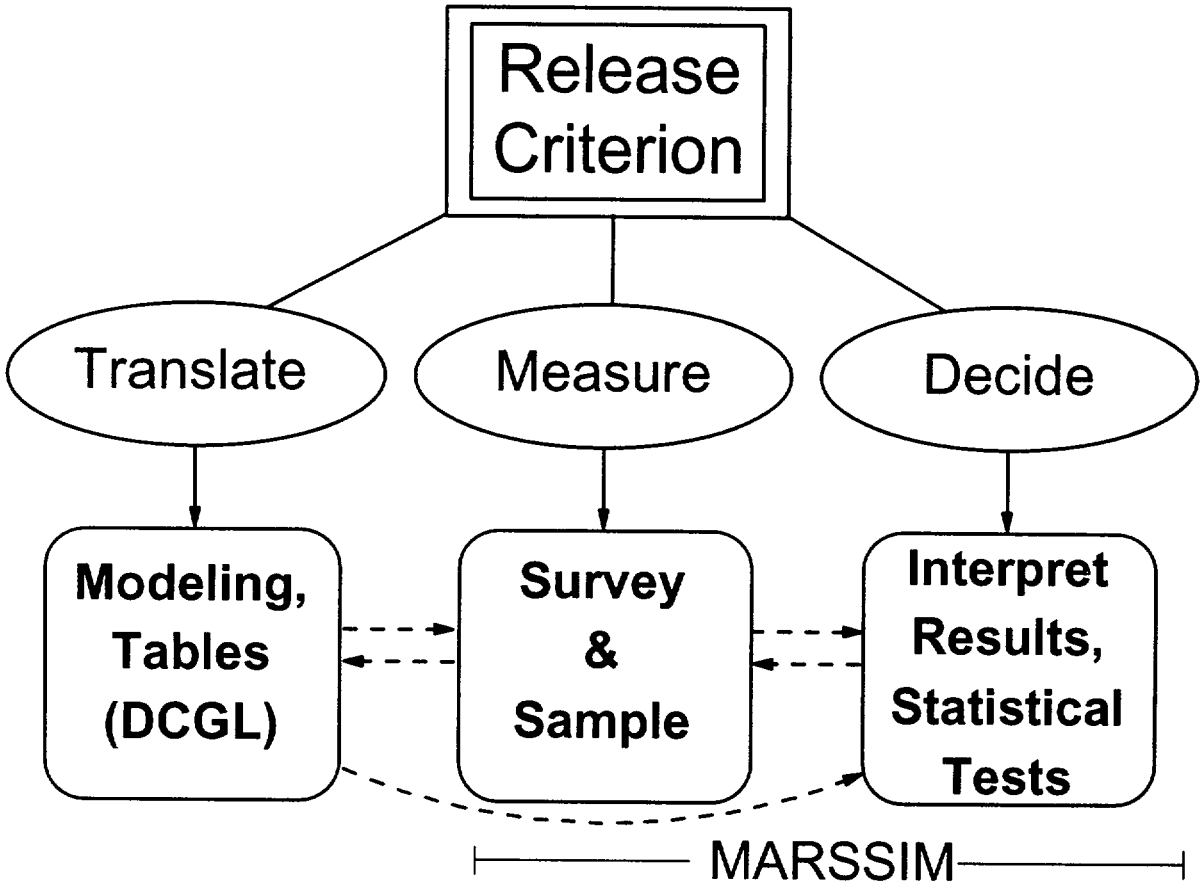

Figure 1.1 Compliance Demonstration

II. Measure: Acquiring scientifically sound and defensible site-specific data on the levels and distribution of residual contamination, as well as levels and distribution of radionuclides present as background, by employing suitable field and/or laboratory measurement techniques.[1]

III. Decide: Determining that the data obtained from sampling does support the assertion that the site meets the release criterion, within an acceptable degree of uncertainty, through application of a statistically based decision rule.

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[1] Measurements include field and laboratory analyses, however, MARSSIM leaves detailed discussions of laboratory sample analyses to another manual (*i.e.*, a companion document, the Multi-Agency Radiation Laboratory Analytical Protocols (MARLAP) manual that is currently under development).

MARSSIM presents comprehensive guidance—specifically for II and III above—for contaminated soil and buildings. This guidance describes a performance-based approach for demonstrating compliance with a dose- or risk-based regulation. This approach includes processes that identify data quality needs and may reveal limitations that enter into conducting a survey. The data quality needs stated as Data Quality Objectives (DQOs) include performance measures and goals in relation to a specific intended use of the data (EPA 1997a).

DQOs must be developed on a site-specific basis. However, because of the large variability in the types of radiation sites, it is impossible to provide criteria that apply to every situation. As an example, MARSSIM presents a method for planning, implementing, assessing, and making decisions about regulatory compliance at sites with radioactive contaminants in surface soil and on building surfaces. In particular, MARSSIM describes generally acceptable approaches for:

- planning and designing scoping, characterization, remediation-support, and final status surveys for sites with surface soil and building surface contamination
- Historical Site Assessment (HSA)
- QA/QC in data acquisition and analysis
- conducting surveys
- field and laboratory methods and instrumentation, and interfacing with radiation laboratories
- statistical hypothesis testing, and the interpretation of statistical data
- documentation

Thus, MARSSIM provides standardized and consistent approaches for planning, conducting, evaluating, and documenting environmental radiological surveys, with a specific focus on the final status surveys that are carried out to demonstrate compliance with cleanup regulations. These approaches may not meet the DQOs at every site, so other methods may be used to meet site-specific DQOs, as long as an equivalent level of performance can be demonstrated.

Table 1.1, at the end of Chapter 1, summarizes the scope of MARSSIM. Several issues related to releasing sites are beyond the scope of MARSSIM. These include translation of dose or risk standards into radionuclide specific concentrations, or demonstrating compliance with ground water or surface water regulations. MARSSIM can be applied to surveys performed at vicinity properties—those not under government or licensee control—but the decision to apply the MARSSIM at vicinity properties is outside the scope of MARSSIM. Other contaminated media (*e.g.*, sub-surface soil, building materials, ground water) and the release of contaminated components and equipment are also not addressed by MARSSIM. With MARSSIM's main focus on final status surveys, this manual continues a process of following remediation activities that are intended to remove below-surface contaminants. Therefore, some of the reasons for limiting the scope of the guidance to contaminated surface soils and building surfaces include:
1) contamination is limited to these media for many sites following remediation, 2) since many

sites have surface soil and building surface contamination as the leading source of contamination, existing computer models used for calculating the concentrations based on dose or risk generally consider only surface soils or building surfaces as a source term, and 3) MARSSIM was written in support of cleanup rulemaking efforts for which supporting data are mostly limited to contaminated surface soil and building surfaces.

MARSSIM also recognizes that there may be other factors, such as cost or stakeholder concerns, that have an impact on designing surveys. Guidance on how to address these specific concerns is outside the scope of MARSSIM. Unique site-specific cases may arise that require a modified approach beyond what is presently described in MARSSIM. This includes examples such as: 1) the release of sites contaminated with naturally occurring radionuclides in which the concentrations corresponding to the release criteria are close to the variability of the background and 2) sites where a reference background cannot be established. However, the process of planning, implementing, assessing, and making decisions about a site described in MARSSIM is applicable to all sites, even if the examples in this manual do not meet a site's specific objectives.

Of MARSSIM's many topics, the Data Quality Objective (DQO) approach to data acquisition and analysis and the Data Quality Assessment (DQA) for determining that data meet stated objectives are two elements that are a consistent theme throughout the manual. The DQO Process and DQA approach, described in Chapter 2, present a method for building common sense and the scientific method into all aspects of designing and conducting surveys, and making best use of the obtainable information. This becomes a formal framework for systematizing the planning of data acquisition surveys so that the data sought yield the kind of information actually needed for making important decisions—such as whether or not to release a particular site following remediation.

1.2 Structure of the Manual

MARSSIM begins with the overview of the Radiation Survey and Site Investigation Process in Chapter 2—Figures 2.4 through 2.8 are flowcharts that summarize the steps and decisions taken in the process. Chapter 3 provides instructions for performing an Historical Site Assessment (HSA)—a detailed investigation to collect existing information on the site or facility and to develop a conceptual site model. The results of the HSA are used to plan surveys, perform measurements, and collect additional information at the site. Chapter 4 covers issues that arise in all types of surveys. Detailed information on performing specific types of surveys is included in Chapter 5. Guidance on selecting the appropriate instruments and measurement techniques for each type of measurement is in Chapters 6 and 7. Chapter 6 discusses direct measurements and scanning surveys, and Chapter 7 discusses sampling and sample preparation for laboratory measurements. The interpretation of survey results is described in Chapter 8. Chapter 9 provides guidance on data management, quality assurance (QA), and quality control (QC). Information on specific subjects related to radiation site investigation can be found in the appendices.

MARSSIM contains several appendices to provide additional guidance on specific topics. Appendix A presents an example of how to apply the MARSSIM guidance to a specific site. Appendix B describes a simplified procedure for compliance demonstration that may be applicable at certain types of sites. Appendix C summarizes the regulations and requirements associated with radiation surveys and site investigations for each of the agencies involved in the development of MARSSIM. Detailed guidance on the DQO Process is in Appendix D, and Appendix E has guidance on DQA. Appendix F describes the relationships among MARSSIM, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and the Resource Conservation and Recovery Act (RCRA). Sources of information used during site assessment are listed in Appendix G. Appendix H describes field survey and laboratory analysis equipment that may be used for radiation surveys and site investigations. Appendix I offers tables of statistical data and supporting information for interpreting survey results described in Chapter 8. The derivation of the alpha scanning detection limit calculations used in Chapter 6 is described in Appendix J. Comparison tables for QA documents are in Appendix K. Appendix L lists the regional radiation program managers for each of the agencies participating in the development of MARSSIM. Appendix M lists publications that serve as resources describing sampling methods. Information on data validation is provided in Appendix N.

MARSSIM is presented in a modular format, with each module containing guidance on conducting specific aspects of, or activities related to, the survey process. Followed in order, each module leads to the generation and implementation of a complete survey plan. Although this approach may involve some overlap and redundancy in information, it also allows many users to concentrate only on those portions of the manual that apply to their own particular needs or responsibilities. The procedures within each module are listed in order of performance and options are provided to guide a user past portions of the manual that may not be specifically applicable to the user's area of interest. Where appropriate, checklists condense and summarize major points in the process. The checklists may be used to verify that every suggested step is followed or to flag a condition in which specific documentation should explain why a step was not needed.

Also included in the manual is a section titled Roadmap. The roadmap is designed to be used with MARSSIM as a quick reference for users already familiar with the process of planning and performing radiation surveys. The roadmap gives the user basic guidance, rules of thumb, and references to sections in the manual containing detailed guidance.

MARSSIM, which is based on a graded approach, also contains a simplified procedure (see Appendix B) that many users of radioactive materials may—with the approval of the responsible regulatory agency—be able to employ to demonstrate compliance with the release criterion. Sites that may qualify for simplified release procedures are those in which the radioactive materials used were 1) of relatively short half-life (*e.g.*, $t_{1/2} \leq 120$ days) and have since decayed to insignificant quantities, 2) kept only in small enough quantities so as to be exempted or not requiring a specific

license from a regulatory authority, 3) used or stored only in the form of non-leaking sealed sources, or 4) combinations of the above.

1.3 Use of the Manual

Potential users of this manual are Federal, State, and local government agencies having authority for control of radioactive environmental contamination; their contractors; and other parties, such as organizations with licensed authority to possess and use radioactive materials. The manual is intended for a technical audience having knowledge of radiation health physics and an understanding of statistics as well as experience with the practical applications of radiation protection. An understanding of instrumentation and methodologies and expertise in planning, approving, and implementing surveys of environmental levels of radioactive material is assumed. This manual has been written so that individuals responsible for planning, approving, and implementing radiological surveys will be able to understand and apply the guidance provided here. Certain situations and sites may require consultation with more experienced personnel.

MARSSIM provides guidance for conducting radiation surveys and site investigations. MARSSIM uses the word "should" as a recommendation, that ought not be interpreted as a requirement. The reader need not expect that every recommendation in this manual will be taken literally and applied at every site. Rather, it is expected that the survey planning documentation will address how the guidance will be applied on a site-specific basis.

As previously stated, MARSSIM supports implementation of dose- or risk-based regulations. The translation of the regulatory dose limit to a corresponding concentration level is not addressed in MARSSIM, so the guidance in this manual is applicable to a broad range of regulations, including risk- or concentration-based regulations. The terms dose and dose-based regulation are used throughout the manual, but these terms are not intended to limit the use of the manual.

Note that Federal or State agencies that can approve a demonstration of compliance may support requirements that differ from what is presented in this version of MARSSIM . *It is essential*, therefore, *that the persons carrying out the surveys*, whether they are conducting surveys in accordance with the simplified approach of Appendix B or the full MARSSIM process, *remain in close communication with the proper Federal or State authorities throughout the compliance demonstration process.*

1.4 Missions of the Federal Agencies Producing MARSSIM

MARSSIM is the product of a multi-agency workgroup with representatives from EPA, NRC, DOE, and DOD. This section briefly describes the missions of the participating agencies. Regulations and requirements governing site investigations for each of the agencies associated with radiation surveys and site investigations are presented in Appendix C.

1.4.1 Environmental Protection Agency

The mission of the U.S. Environmental Protection Agency (EPA) is to improve and preserve the quality of the environment, on both national and global levels. The EPA's scope of responsibility includes implementing and enforcing environmental laws, setting guidelines, monitoring pollution, performing research, and promoting pollution prevention. EPA Headquarters maintains overall planning, coordination, and control of EPA programs, and EPA's ten regional offices are responsible for executing EPA's programs within the boundaries of each region. EPA also coordinates with, and supports research and development of, pollution control activities carried out by State and local governments.

1.4.2 Nuclear Regulatory Commission

The mission of the U.S. Nuclear Regulatory Commission (NRC) is to ensure adequate protection of public health and safety, the common defense and security, and the environment in the use of certain radioactive materials in the United States. The NRC's scope of responsibility includes regulation of commercial nuclear power reactors; non-power research, test, and training reactors; fuel cycle facilities; medical, academic, and industrial uses of nuclear materials; and the transport, storage, and disposal of nuclear materials and waste. The Energy Reorganization Act of 1974 and the Atomic Energy Act of 1954, as amended, provide the foundation for regulation of the Nation's commercial use of radioactive materials.

1.4.3 Department of Energy

The mission of the Department of Energy (DOE) is to develop and implement a coordinated national energy policy to ensure the availability of adequate energy supplies and to develop new energy sources for domestic and commercial use. In addition, DOE is responsible for the development, construction and testing of nuclear weapons for the U.S. Military. DOE is also responsible for managing the low- and high-level radioactive wastes generated by past nuclear weapons and research programs and for constructing and maintaining a repository for civilian radioactive wastes generated by the commercial nuclear reactors. DOE has the lead in decontaminating facilities and sites previously used in atomic energy programs.

1.4.4 Department of Defense

The global mission of the Department of Defense (DOD) is to provide for the defense of the United States. In doing this, DOD is committed to protecting the environment. Each military service has specific regulations addressing the use of radioactive sources and the development of occupational health programs and radiation protection programs. The documents describing these regulations are used as guidance in developing environmental radiological surveys within DOD and are discussed in Appendix C.

Table 1.1 Scope of MARSSIM

Within Scope of MARSSIM		Beyond Scope of MARSSIM	
Guidance	MARSSIM provides technical guidance on conducting radiation surveys and site investigations.	*Regulation*	MARSSIM does not set new regulations or non-technical issues (*e.g.*, legal or policy) for site cleanup. Release criterion will be provided rather than calculated using MARSSIM.
Tool Box	MARSSIM can be thought of as an extensive tool box with many components—some within the text of MARSSIM, others by reference.	*Tool Box*	Many topics are beyond the scope of MARSSIM, for example: -a public participation program -packaging and transportation of wastes for disposal -decontamination and stabilization techniques -training
Measurement	The guidance given in MARSSIM is performance-based and directed towards acquiring site-specific data.	*Procedure*	The approaches suggested in MARSSIM vary depending on the various site data needs—there are no set procedures for sample collection, measurement techniques, storage and disposal established in MARSSIM.
Modeling	The interface between environmental pathway modeling and MARSSIM is an important survey design consideration addressed in MARSSIM.	*Modeling*	Environmental pathway modeling and ecological endpoints in modeling are beyond the scope of MARSSIM.

Table 1.1 Scope of MARSSIM (continued)

Within Scope of MARSSIM		Beyond Scope of MARSSIM	
Soil and Buildings	The two main media of interest in MARSSIM are contaminated surface soil and building surfaces.	*Other Media*	MARSSIM does not cover other media, including construction materials, equipment, subsurface soil, surface or subsurface water, biota, air, sewers, sediments or volumetric contamination.
Final Status Survey	The focus of MARSSIM is on the final status survey as this is the deciding factor in judging if the site meets the release criterion.	*Materials or Equipment*	MARSSIM does not recommend the use of any specific materials or equipment—there is too much variability in the types of radiation sites—this information will be in other documents.
Radiation	MARSSIM only considers radiation-derived hazards.	*Chemicals*	MARSSIM does not deal with any hazards posed by chemical contamination.
Remediation Method	MARSSIM assists users in determining when sites are ready for a final status survey and provides guidance on how to determine if remediation was successful.	*Remediation Method*	MARSSIM does not discuss selection and evaluation of remedial alternatives, public involvement, legal considerations, policy decisions related to planning
DQO Process	MARSSIM presents a systemized approach for designing surveys to collect data needed for making decisions such as whether or not to release a site.	*DQO Process*	MARSSIM does not provide prescriptive or default values of DQOs.
DQA	MARSSIM provides a set of statistical tests for evaluating data and lists alternate tests that may be applicable at specific sites.	*DQA*	MARSSIM does not prescribe a statistical test for use at all sites.

2 OVERVIEW OF THE RADIATION SURVEY AND SITE INVESTIGATION PROCESS

2.1 Introduction

This chapter provides a brief overview of the Radiation Survey and Site Investigation (RSSI) Process, several important aspects of this Process, and its underlying principles. The concepts introduced here are discussed in detail throughout the manual.

The purpose of MARSSIM is to provide a standardized approach to demonstrating compliance with a dose- or risk-based regulation. Since most of the manual is based on general technical and statistical concepts, much of the guidance can still be applied to other types of regulations or standards. The purpose of this chapter is to provide the overview information required to understand the rest of this manual.

Section 2.2 introduces and defines key terms used throughout the manual. Some of these terms may be familiar to the MARSSIM user, while others are new terms developed specifically for this manual.

Section 2.3 describes the flow of information used to decide whether or not a site or facility complies with a regulation. The section describes the framework that is used to demonstrate compliance with a regulation, and is the basis for all guidance presented in this manual. The decision-making process is broken down into four phases: 1) planning, 2) implementation, 3) assessment, and 4) decision making.

Section 2.4 introduces the Radiation Survey and Site Investigation Process, which can be used for compliance demonstration at many sites. The section describes a series of surveys that combine to form the core of this process. Each survey has specified goals and objectives to support a final decision on whether or not a site or facility complies with the appropriate regulations. Flow diagrams showing how the different surveys support the overall process are provided, along with descriptions of the information provided by each type of survey.

Section 2.5 presents major considerations that relate to the decision-making and survey-design processes. This section, as well as the examples discussed in detail throughout the manual, focuses on residual radioactive contamination in surface soils and on building surfaces. Recommended survey designs for demonstrating compliance are presented along with the rationale for selecting these designs.

Section 2.6 recognizes that the methods presented in MARSSIM may not represent the optimal survey design at all sites. Some alternate methods for applying the Radiation Survey and Site Investigation process are discussed. Different methods for demonstrating compliance that are technically defensible may be developed with the approval of the responsible regulatory agency.

MARSSIM provides an approach that is technically defensible and flexible enough to be applied to a variety of site-specific conditions. Applying this guidance to a dose- or risk-based regulation provides a consistent approach to protecting human health and the environment. The manual's performance-based approach to decision making provides the flexibility needed to address compliance demonstration at individual sites.

2.2 Understanding Key MARSSIM Terminology

The first step in understanding the Radiation Survey and Site Investigation (RSSI) Process is accomplished by understanding the scope of this manual, the terminology, and the concepts set forth. Some of the terms used in MARSSIM were developed for the purposes of this manual, while other commonly used terms are also adopted for use in MARSSIM. This section explains some of the terms roughly in the order of their presentation in the manual.

The process described in MARSSIM begins with the premise that a release criterion has already been provided in terms of a measurement quantity. The methods presented in MARSSIM are generally applicable and are not dependent on the value of the release criterion.

A *release criterion* is a regulatory limit expressed in terms of dose (mSv/y or mrem/y) or risk (cancer incidence or cancer mortality). The terms release limit or cleanup standard are also used to describe this term. A release criterion is typically based on the total effective dose equivalent (TEDE), the committed effective dose equivalent (CEDE), risk of cancer incidence (morbidity), or risk of cancer death (mortality) and generally cannot be measured directly. *Exposure pathway modeling* is used to calculate a radionuclide-specific predicted concentration or surface area concentration of specific nuclides that could result in a dose (TEDE or CEDE) or specific risk equal to the release criterion. In this manual, such a concentration is termed the *derived concentration guideline level (DCGL)*. Exposure pathway modeling is an analysis of various exposure pathways and scenarios used to convert dose or risk into concentration. In many cases DCGLs can be obtained from responsible regulatory agency guidance based on default modeling input parameters, while other users may elect to take into account site-specific parameters to determine DCGLs. In general, the units for the DCGL are the same as the units for measurements performed to demonstrate compliance (*e.g.*, Bq/kg or pCi/g, Bq/m^2 or dpm/100 cm^2). This allows direct comparisons between the survey results and the DCGL. A discussion of the uncertainty associated with using DCGLs to demonstrate compliance is included in Appendix D, Section D.6.

An *investigation level* is a radionuclide-specific level based on the release criterion that, if exceeded, triggers some response such as further investigation or remediation. An investigation level may be used early in decommissioning to identify areas requiring further investigation, and may also be used as a screening tool during compliance demonstration to identify potential problem areas. A DCGL is an example of a specific investigation level.

While the derivation of DCGLs is outside the scope of MARSSIM, it is important to understand the assumptions that underlie this derivation. The derivation assumptions must be consistent with those used for planning a compliance demonstration survey. One of the most important assumptions used for converting a dose or risk limit into a media-specific concentration is the modeled area of contamination. Other considerations include sample depth, composition, modeling parameters, and exposure scenarios. MARSSIM defines two potential DCGLs based on the area of contamination.

- If the residual radioactivity is evenly distributed over a large area, MARSSIM looks at the average activity over the entire area. The $DCGL_W$[1] (the DCGL used for the statistical tests, see Section 2.5.1.2) is derived based on an average concentration over a large area.

- If the residual radioactivity appears as small areas of elevated activity[2] within a larger area, typically smaller than the area between measurement locations, MARSSIM considers the results of individual measurements. The $DCGL_{EMC}$ (the DCGL used for the elevated measurement comparison (EMC), see Section 2.5.3 and Section 2.5.4) is derived separately for these small areas and generally from different exposure assumptions than those used for larger areas.

A *site* is any installation, facility, or discrete, physically separate parcel of land, or any building or structure or portion thereof, that is being considered for survey and investigation.

Area is a very general term that refers to any portion of a site, up to and including the entire site.

Decommissioning is the process of safely removing a site from service, reducing residual radioactivity through remediation to a level that permits release of the property, and termination of the license or other authorization for site operation. Although only part of the process, the term decommissioning is used in this sense for the Radiation Survey and Site Investigation (RSSI) Process, and is used this way throughout MARSSIM.

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[1] The "W" in $DCGL_W$ stands for Wilcoxon Rank Sum test, which is the statistical test recommended in MARSSIM for demonstrating compliance when the contaminant is present in background. The Sign test recommended for demonstrating compliance when the contaminant is not present in background also uses the $DCGL_W$.

[2] A small area of elevated activity, or maximum point estimate of contamination, might also be referred to as a "hot spot." This term has been purposefully omitted from MARSSIM because the term often has different meanings based on operational or local program concerns. As a result, there may be problems associated with defining the term and reeducating MARSSIM users in the proper use of the term. Because these implications are inconsistent with MARSSIM concepts, the term is not used.

A *survey unit* is a physical area consisting of structure or land areas of specified size and shape for which a separate decision will be made as to whether or not that area exceeds the release criterion. This decision is made as a result of the *final status survey*—the survey in the RSSI Process used to demonstrate compliance with the regulation or standard. The size and shape of the survey unit are based on factors, such as the potential for contamination, the expected distribution of contamination, and any physical boundaries (*e.g.*, buildings, fences, soil type, surface water body) at the site.

For MARSSIM, *measurement* is used interchangeably to mean: 1) the act of using a detector to determine the level or quantity of radioactivity on a surface or in a sample of material removed from a media being evaluated, or 2) the quantity obtained by the act of measuring. *Direct measurements* are obtained by placing a detector near the media being surveyed and inferring the radioactivity level directly from the detector response. *Scanning* is a measurement technique performed by moving a portable radiation detector at a constant speed above a surface to semi-quantitatively detect areas of elevated activity. *Sampling* is the process of collecting a portion of an environmental medium as being representative of the locally remaining medium. The collected portion, or aliquot, of the medium is then analyzed to identify the contaminant and determine the concentration. The word sample may also refer to a set of individual measurements drawn from a population whose properties are studied to gain information about the entire population. This second definition of sample is primarily used for statistical discussions.

To make the best use of resources for decommissioning, MARSSIM places greater survey efforts on areas that have, or had, the highest potential for contamination. This is referred to as a *graded approach*. The final status survey uses statistical tests to support decision making. These statistical tests are performed using survey data from areas with common characteristics, such as contamination potential, which are distinguishable from other areas with different characteristics. *Classification* is the process by which an area or survey unit is described according to radiological characteristics. The significance of survey unit classification is that this process determines the final status survey design and the procedures used to develop this design. Preliminary area classifications, made earlier in the MARSSIM Process, are useful for planning subsequent surveys.

Areas that have no reasonable potential for residual contamination are classified as *non-impacted areas*. These areas have no radiological impact from site operations and are typically identified early in decommissioning. Areas with some potential for residual contamination are classified as *impacted areas*.

Impacted areas are further divided into one of three classifications:

- *Class 1 Areas*: Areas that have, or had prior to remediation, a potential for radioactive contamination (based on site operating history) or known contamination (based on previous radiation surveys) above the $DCGL_W$. Examples of Class 1 areas include: 1) site areas previously subjected to remedial actions[3], 2) locations where leaks or spills are known to have occurred, 3) former burial or disposal sites, 4) waste storage sites, and 5) areas with contaminants in discrete solid pieces of material and high specific activity.

- *Class 2 Areas*: Areas that have, or had prior to remediation, a potential for radioactive contamination or known contamination, but are not expected to exceed the $DCGL_W$. To justify changing the classification from Class 1 to Class 2, there should be measurement data that provides a high degree of confidence that no individual measurement would exceed the $DCGL_W$. Other justifications for reclassifying an area as Class 2 may be appropriate, based on site-specific considerations. Examples of areas that might be classified as Class 2 for the final status survey include: 1) locations where radioactive materials were present in an unsealed form, 2) potentially contaminated transport routes, 3) areas downwind from stack release points, 4) upper walls and ceilings of buildings or rooms subjected to airborne radioactivity, 5) areas handling low concentrations of radioactive materials, and 6) areas on the perimeter of former contamination control areas.

- *Class 3 Areas*: Any impacted areas that are not expected to contain any residual radioactivity, or are expected to contain levels of residual radioactivity at a small fraction of the $DCGL_W$, based on site operating history and previous radiation surveys. Examples of areas that might be classified as Class 3 include buffer zones around Class 1 or Class 2 areas, and areas with very low potential for residual contamination but insufficient information to justify a non-impacted classification.

Class 1 areas have the greatest potential for contamination and therefore receive the highest degree of survey effort for the final status survey using a graded approach, followed by Class 2, and then by Class 3. Non-impacted areas do not receive any level of survey coverage because they have no potential for residual contamination. Non-impacted areas are determined on a site-specific basis. Examples of areas that would be non-impacted rather than impacted usually include residential or other buildings that have or had nothing more than smoke detectors or exit signs with sealed radioactive sources.

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[3] Remediated areas are identified as Class 1 areas because the remediation process often results in less than 100% removal of the contamination, even though the goal of remediation is to comply with regulatory standards and protect human health and the environment. The contamination that remains on the site after remediation is often associated with relatively small areas with elevated levels of residual radioactivity. This results in a non-uniform distribution of the radionuclide and a Class 1 classification. If an area is expected to have no potential to exceed the $DCGL_W$ and was remediated to demonstrate the residual radioactivity is as low as reasonably achievable (ALARA), the remediated area might be classified as Class 2 for the final status survey.

If the radionuclide of potential concern is present in background, or if the measurement system used to determine concentration in the survey unit is not radionuclide-specific, background measurements are compared to the survey unit measurements to determine the level of residual radioactivity. The *background reference area* is a geographical area from which representative reference measurements are performed for comparison with measurements performed in specific survey units. The background reference area is defined as an area that has similar physical, chemical, radiological, and biological characteristics as the survey unit(s) being investigated but has not been contaminated by site activities (*i.e.*, non-impacted).

The process of planning the survey, implementing the survey plan, and assessing the survey results prior to making a decision is called the *Data Life Cycle*. Survey planning uses the *Data Quality Objectives (DQO) Process* to ensure that the survey results are of sufficient quality and quantity to support the final decision. *Quality Assurance and Quality Control (QA/QC)* procedures are performed during implementation of the survey plan to collect information necessary to evaluate the survey results. *Data Quality Assessment* (DQA) is the process of assessing the survey results, determining that the quality of the data satisfies the objectives of the survey, and interpreting the survey results as they apply to the decision being made.

A systematic process and structure for quality should be established to provide confidence in the quality and quantity of data collected to support decision making. The data used in decision making should be supported by a planning document that records how quality assurance and quality control are applied to obtain type and quality of results that are needed and expected. There are several terms used to describe a variety of planning documents, some of which document only a small part of the survey design process. MARRSIM uses the term *Quality Assurance Project Plan* (QAPP) to describe a single document that incorporates all of the elements of the survey design. This term is consistent with consensus guidance ANSI/ASQC E4-1994 (ASQC 1995) and EPA guidance (EPA 1994c; EPA 1997a), and is recommended to promote consistency. The use of the term QAPP in MARSSIM does not exclude the use of other terms (*e.g.*, Decommissioning Plan, Sampling and Analysis Plan, Field Sampling Plan) to describe survey documentation provided the information included in the documentation supports the objectives of the survey.

2.3 Making Decisions Based on Survey Results

Compliance demonstration is simply a decision as to whether or not a survey unit meets the release criterion. For most sites this decision is based on the results of one or more surveys. When survey results are used to support a decision, the decision maker[4] needs to ensure that the

[4] The term decision maker is used throughout this section to describe the person, team, board, or committee responsible for the final decision regarding disposition of the survey unit.

data will support that decision with satisfactory confidence. Usually a decision maker will make a correct decision after evaluating the data. However, since uncertainty in the survey results is unavoidable, the possibility of errors in decisions supported by survey results is unavoidable. For this reason, positive actions must be taken to manage the uncertainty in the survey results so that sound, defensible decisions may be made. These actions include proper survey planning to control known causes of uncertainty, proper application of quality control (QC) procedures during implementation of the survey plan to detect and control significant sources of error , and careful analysis of uncertainty before the data are used to support decision making. These actions describe the flow of data throughout each type of survey, and are combined in the Data Life Cycle as shown in Figure 2.1.

There are four phases of the Data Life Cycle:

- *Planning Phase.* The survey design is developed and documented using the Data Quality Objectives (DQO) Process. Quality assurance and quality control (QA/QC) procedures are developed and documented in the Quality Assurance Project Plan (QAPP). The QAPP is the principal product of the planning process which incorporates the DQOs as it integrates all technical and quality aspects for the life cycle of the project, including planning, implementation, and assessment. The QAPP documents planning results for survey operations and provides a specific format for obtaining the type and quality of data needed for decision making. The QAPP elements are presented in an order corresponding to the Data Life Cycle by grouping them into two types of elements: 1) project management; and 2) collection and evaluation of environmental data (ASQC 1995). The DQO process is described in Appendix D, and applied in Chapters 3, 4, and 5 of this manual. Development of the QAPP is described in Section 9.2 and applied throughout decommissioning.

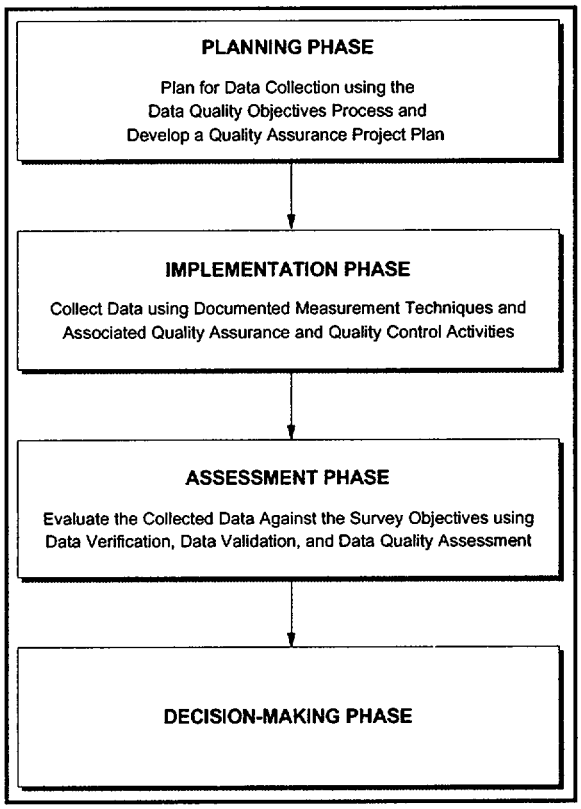


Figure 2.1 The Data Life Cycle

- *Implementation Phase.* The survey design is carried out in accordance with the SOPs and QAPP, resulting in the generation of raw data. Chapter 6, Chapter 7, and Appendix H provide information on the selection of data collection techniques. The QA and QC measurements, discussed in Chapter 6 and Chapter 7, also generate data and other important information that will be used during the Assessment Phase.

- *Assessment Phase.* The data generated during the Implementation Phase are first verified to ensure that the SOPs specified in the QAPP were actually followed and that the measurement systems performed in accordance with the criteria specified in the QAPP. Then the data are validated to ensure that the results of data collection activities support the objectives of the survey as documented in the QAPP, or permit a determination that these objectives should be modified. The data quality assessment (DQA) process is then applied using the validated data to determine if the quality of the data satisfies the data user's needs. Data verification and validation are described in Section 9.3. The DQA process is described in Appendix E and is applied in Chapter 8.

- *Decision-Making Phase.* A decision is made, in coordination with the responsible regulatory agency, based on the conclusions drawn from the assessment process. The ultimate objective is to make technically defensible decisions with a specified level of confidence (Chapter 8).

2.3.1 Planning Effective Surveys—Planning Phase

The first step in designing effective surveys is planning. The DQO Process is a series of planning steps based on the scientific method for establishing criteria for data quality and developing survey designs (ASQC 1995, EPA 1994a, EPA 1987b, EPA 1987c). Planning radiation surveys using the DQO Process improves the survey effectiveness and efficiency, and thereby the defensibility of decisions. This minimizes expenditures related to data collection by eliminating unnecessary, duplicative, or overly precise data. Using the DQO Process ensures that the type, quantity, and quality of environmental data used in decision making will be appropriate for the intended application. MARSSIM supports the use of the DQO Process to design surveys for input to both evaluation techniques (elevated measurement comparison and the statistical test). The DQO Process provides systematic procedures for defining the criteria that the survey design should satisfy, including what type of measurements to perform, when and where to perform measurements, the level of decision errors for the survey, and how many measurements to perform.

The level of effort associated with planning a survey is based on the complexity of the survey. Large, complicated sites generally receive a significant amount of effort during the planning phase, while smaller sites may not require as much planning. This graded approach defines data quality requirements according to the type of survey being designed, the risk of making a decision

error based on the data collected, and the consequences of making such an error. This approach provides a more effective survey design combined with a basis for judging the usability of the data collected.

DQOs are qualitative and quantitative statements derived from the outputs of the DQO Process that:

- clarify the study objective
- define the most appropriate type of data to collect
- determine the most appropriate conditions for collecting the data
- specify limits on decision errors which will be used as the basis for establishing the quantity and quality of data needed to support the decision

The DQO Process consists of seven steps, as shown in Figure 2.2. Each step is discussed in detail in Appendix D. While all of the outputs of the DQO Process are important for designing efficient surveys, there are some that are referred to throughout the manual. These DQOs are mentioned briefly here, and are discussed in detail throughout MARSSIM and in Appendix D.

The minimum information (outputs) required from the DQO Process to proceed with the methods described in MARSSIM are:

- classify and specify boundaries of survey units: this can be accomplished at any time, but must be finalized during final status survey planning (Section 4.4, Section 4.6)
- state the null hypothesis (H_0): the residual radioactivity in the survey unit exceeds the release criterion (Section 2.5, Appendix D, Section D.6)
- specify a gray region where the consequences of decision errors are relatively minor: the upper bound of the gray region is defined as the $DCGL_W$, and the lower bound of the gray region (LBGR) is a site-specific variable generally initially selected to equal one half the $DCGL_W$ and adjusted to provide an acceptable value for the relative shift (Section 5.5.2.2, Section 5.5.2.3, Appendix D, Section D.6)
- define Type I and Type II decision errors and assign probability limits for the occurrence of these errors: the probability of making a Type I decision error (α) or a Type II decision error (β) are site-specific variables (Section 5.5.2.2, Section 5.5.2.3, Appendix D, Section D.6)
- estimate the standard deviation of the measurements in the survey unit: the standard deviation (σ) is a site-specific variable, typically estimated from preliminary survey data (Section 5.5.2.2, Section 5.5.2.3)
- specify the relative shift: the shift (Δ) is equal to the width of the gray region ($DCGL_W$ - LBGR), and the relative shift is defined as Δ/σ, which is generally designed to have a value between one and three (Section 5.5.2.2, Section 5.5.2.3)

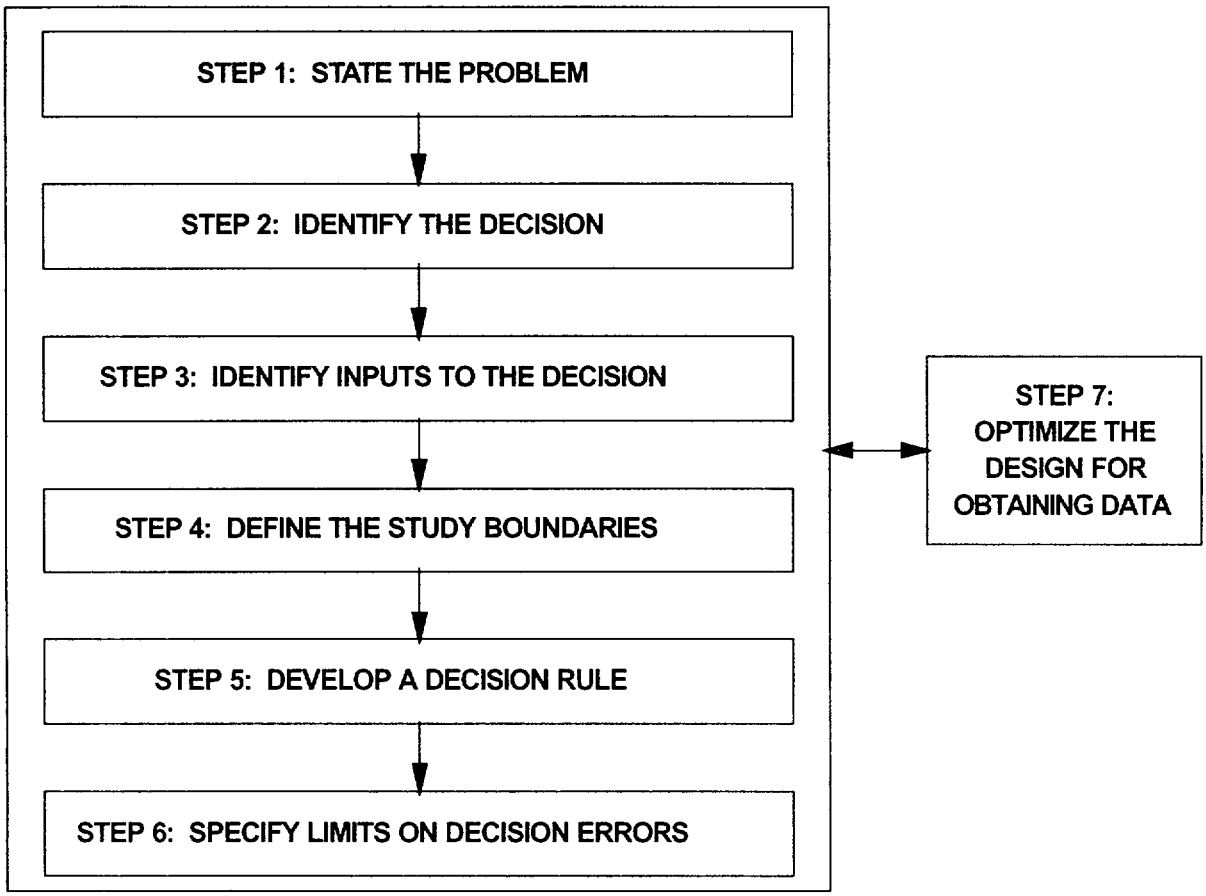


Figure 2.2 The Data Quality Objectives Process

- specify the detection limit for all measurement techniques (scanning, direct measurement, and sample analysis) specified in the QAPP: the minimum detectable concentration (MDC) is unique for each measurement system (Section 6.7)
- calculate the estimated number of measurements (N) and specify the measurement locations required to demonstrate compliance: the number of measurements depends on the relative shift (Δ/σ), Type I and Type II decision error rates (α and β), the potential for small areas of elevated activity, and the selection and classification of survey units (Section 5.5.2.2, Section 5.5.2.3)
- specify the documentation requirements for the survey, including survey planning documentation: documentation supporting the decision on whether or not the site complies with the release criterion is determined on a site-specific basis (Appendix N, Section N.2)

In addition to DQOs, values for the Data Quality Indicators (DQIs) should also be established and recorded during the planning stage. Where DQOs include performance measures and goals in relation to a specific intended use of the data, DQIs quantify the amount of error in the data collection process and the analytical measurement system regardless of how the data may be used (EPA 1997a). Precision, bias, accuracy, representativeness, comparability, and completeness are the DQIs recommended for quantifying the amount of error for survey data. These DQIs are discussed in detail in Appendix N, Section N.6.

2.3.2 Estimating the Uncertainty in Survey Results—Implementation Phase

To encourage flexibility and the use of optimal measurement techniques for a specific site, MARSSIM does not provide detailed guidance on specific techniques. Instead, MARSSIM encourages the decision maker to evaluate available techniques based on the survey objectives. Guidance on evaluating these objectives, such as detection limit, is provided.

QC programs can both lower the chances of making an incorrect decision and help the data user understand the level of uncertainty that surrounds the decision (EPA 1997a). As discussed previously, QC data are collected and analyzed during implementation to provide an estimate of the uncertainty associated with the survey results. QC measurements (scans, direct measurements, and samples) are technical activities performed to measure the attributes and performance of the survey. During any survey, a certain number of measurements should be taken for QC purposes.

2.3.3 Interpreting Survey Results—Assessment Phase

Assessment of environmental data is used to evaluate whether the data meet the objectives of the survey and whether the data are sufficient to determine compliance with the DCGL (EPA 1992a, EPA 1992b, EPA 1996a). The assessment phase of the Data Life Cycle consists of three phases: data verification, data validation, and Data Quality Assessment (DQA).

Data verification is used to ensure that the requirements stated in the planning documents are implemented as prescribed (see Section 9.3). Data validation is used to ensure that the results of the data collection activities support the objectives of the survey as documented in the QAPP, or permit a determination that these objectives should be modified (see Section 9.3 and Appendix N). Data quality assessment (DQA) is the scientific and statistical evaluation of data to determine if the data are of the right type, quality, and quantity to support their intended use (EPA 1996a). DQA helps complete the Data Life Cycle by providing the assessment needed to determine that the planning objectives are achieved (see Section 8.2). Figure 2.3 illustrates where data verification, data validation, and DQA fit into the Assessment Phase of the Data Life Cycle.

There are five steps in the DQA Process:

- Review the DQOs and Survey Design
- Conduct a Preliminary Data Review
- Select the Statistical Test
- Verify the Assumptions of the Statistical Test
- Draw Conclusions from the Data

The strength of DQA is its design that progresses in a logical and efficient manner to promote an understanding of how well the data meet the intended use. The Assessment Phase is described in more detail in Appendix E. Section 2.6 discusses the flexibility of the Data Life Cycle and describes the use of survey designs other than those described later in MARSSIM.

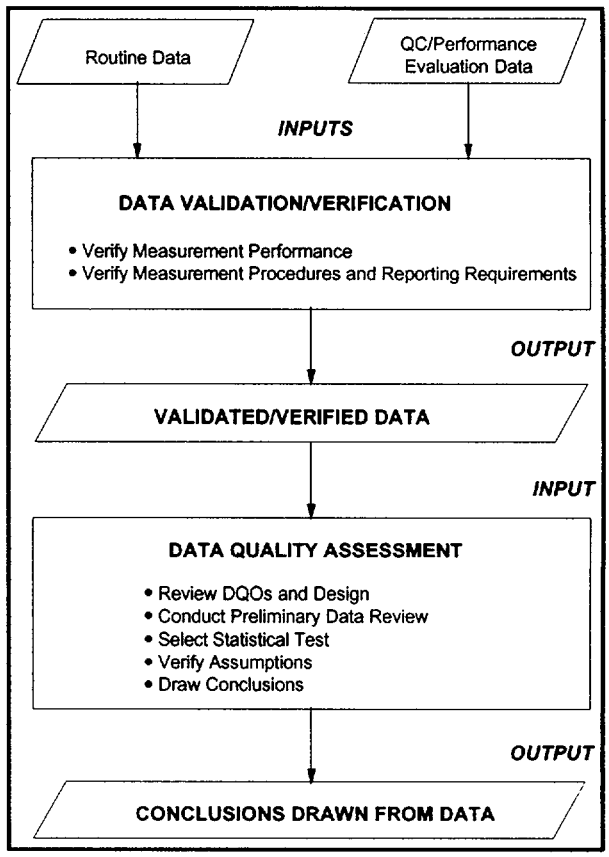


Figure 2.3 The Assessment Phase of the Data Life Cycle (EPA 1996a)

2.3.4 Uncertainty in Survey Results

Uncertainty in survey results arises primarily from two sources: survey design errors and measurement errors. Survey design errors occur when the survey design is unable to capture the complete extent of variability that exists for the radionuclide distribution in a survey unit. Since it is impossible in every situation to measure the residual radioactivity at every point in space and time, the survey results will be incomplete to some degree. It is also impossible to know with complete certainty the residual radioactivity at locations that were not measured, so the incomplete survey results give rise to uncertainty. The greater the natural or inherent variation in residual radioactivity, the greater the uncertainty associated with a decision based on the survey results. The unanswered question is: "How well do the survey results represent the true level of residual radioactivity in the survey unit?"

Measurement errors create uncertainty by masking the true level of residual radioactivity and may be classified as random or systematic errors. Random errors affect the precision of the measurement system, and show up as variations among repeated measurements. Systematic errors show up as measurements that are biased to give results that are consistently higher or lower than the true value. Measurement uncertainty is discussed in Section 6.8.

MARSSIM uses the Data Life Cycle to control and estimate the uncertainty in the survey results on which decisions are made. Adequate planning should minimize known sources of uncertainty. QC data collected during implementation of the survey plan provide an estimate of the uncertainty. Statistical hypothesis testing during the assessment phase provides a level of confidence for the final decision. There are several levels of decisions included within each survey type. Some decisions are quantitative, based on the numerical results of measurements performed during the survey. Other decisions are qualitative based on the available evidence and best professional judgment. The Data Life Cycle can and should be applied consistently to both types of decisions.

2.3.5 Reporting Survey Results

The process of reporting survey results is an important consideration in planning the survey. Again, the level of effort for reporting should be based on the complexity of the survey. A simple survey with relatively few results may specify a single report, while a more complicated survey may specify several reports to meet the objectives of the survey. Reporting requirements for individual surveys should be developed during planning and clearly documented in the QAPP. These requirements should be developed with cooperation from the people performing the analyses (*e.g.*, the analytical laboratory should be consulted on reporting results for samples). The Health Physics Society has developed several suggestions for reporting survey results (EPA 1980c). These suggestions include:

- Report the actual result of the analysis. Do not report data as "less than the detection limit." Even negative results and results with large uncertainties can be used in the statistical tests to demonstrate compliance. Results reported only as "<MDC" cannot be fully used and, for example, complicate even such simple analyses as calculating an average. While the nonparametric tests described in Section 8.3 and Section 8.4 can accommodate as much as 40% of the results as non-detects, it is better to report the actual results and avoid the possibility of exceeding this limit.

- Report results using the correct units and the correct number of significant digits. The choice of reporting results using SI units (*e.g.*, Bq/kg, Bq/m^2) or conventional units (*e.g.*, pCi/g, dpm/100 cm^2) is made on a site-specific basis. Generally, MARSSIM recommends that all results be reported in the same units as the DCGLs. Sometimes the results may be more convenient to work with as counts directly from the detector. In these cases the user should decide what the appropriate units are for a specific survey based on the survey objectives. The user should also report the correct number of significant digits as described in EPA 1980c.

- Report the measurement uncertainty for every analytical result or series of results, such as for a measurement system. This uncertainty, while not directly used for demonstrating compliance with the release criterion, is used for survey planning and data assessment throughout the Radiation Survey and Site Investigation Process. In addition, the uncertainty is used for evaluating the performance of measurement systems using QC measurement results (as described in Section 6.2 for scans and direct measurements, and in Section 7.2 for laboratory analysis of samples). The uncertainty is also used for comparing individual measurements to the action level, which is especially important in the early stages of decommissioning (scoping, characterization, and remedial action support surveys described in Section 2.4) when decisions are made based on a limited number of measurements. Section 6.8 discusses methods for calculating the measurement uncertainty.

- Report the minimum detectable concentration (MDC) for the measurement system as well as the method used to calculate the MDC. The MDC is an *a priori* estimate of the capability for detecting an activity concentration with a specific measurement system (EPA 1980c). As such, this estimate is valuable for planning and designing radiation surveys. Optimistic estimates of the MDC (calculated using ideal conditions that may not apply to actual measurements) overestimate the ability of a technique to detect residual radioactivity, especially when scanning for alpha or low-energy beta radiations. This can invalidate survey results, especially for scanning surveys. Using a more realistic MDC, as described in Section 6.7, during scoping and characterization surveys helps in the proper classification of survey units for final status surveys and minimizes the possibility of designing and performing subsequent surveys because of errors in classification. Estimates of the MDC that minimize potential decision errors should be used for planning surveys.

Reporting requirements for individual surveys should be developed during planning and clearly documented in the QAPP.

2.4 Radiation Survey and Site Investigation Process

The Data Life Cycle discussed in Section 2.3 is the basis for the performance-based guidance in MARSSIM. As a framework for collecting the information required for demonstrating compliance identified using the DQO Process, MARSSIM recommends using a series of surveys. The Radiation Survey and Site Investigation (RSSI) Process is an example of a series of surveys designed to demonstrate compliance with a dose- or risk-based regulation for sites with radioactive contamination.

There are six principal steps in the RSSI Process:

- Site Identification
- Historical Site Assessment
- Scoping Survey
- Characterization Survey
- Remedial Action Support Survey
- Final Status Survey

Table 2.1 provides a simplified overview of the principal steps in the RSSI process and how the Data Life Cycle can be used in an iterative fashion within the process. Each of these steps is briefly described in the Sections 2.4.1 through 2.4.6, and described in more detail in Chapter 3 and Chapter 5. In addition, there is a brief description of regulatory agency confirmation and verification (see Section 2.4.7). Because MARSSIM focuses on demonstrating compliance with a release criterion, specifically through the use of a final status survey, these surveys have additional objectives that are not fully discussed in MARSSIM (*e.g.*, health and safety of workers, supporting selection of values for exposure pathway model parameters).

Figure 2.4 illustrates the Radiation Survey and Site Investigation Process in terms of area classification, and lists the major decision to be made for each type of survey. The flowchart demonstrates one method for quickly estimating the survey unit classification early in the MARSSIM Process based on limited information. While this figure shows the relationship between area classification and survey unit classification along with the major decision points that determine classification, this illustration is not designed to comprehensively consider every possibility that may occur at individual survey units. As such, it is a useful tool for visualizing the classification process, but there are site-specific characteristics that may cause variation from this scheme.

The flowchart, illustrated in Figures 2.5 through 2.8, presents the principal steps and decisions in the site investigation process and shows the relationship of the survey types to the overall assessment process. As shown in these figures, there are several sequential steps in the site investigation process and each step builds on information provided by its predecessor. Properly applying each sequential step in the RSSI Process should provide a high degree of assurance that the release criterion has not been exceeded.

Table 2.1 The Data Life Cycle used to Support the Radiation Survey and Site Investigation Process

RSSI Process	Data Life Cycle		MARSSIM Guidance
Site Identification			Provides information on identifying potential radiation sites (Section 3.3)
Historical Site Assessment	Historical Site Assessment Data Life Cycle	Plan Implement Assess Decide	Provides information on collecting and assessing existing site data (Sections 3.4 through 3.9) and potential sources of information (Appendix G)
Scoping Survey	Scoping Data Life Cycle	Plan Implement Assess Decide	Discusses the purpose and general approach for performing scoping surveys, especially as sources of information when planning final status surveys (Section 5.2)
Characterization Survey	Characterization Data Life Cycle	Plan Implement Assess Decide	Discusses the purpose and general approach for performing characterization surveys, especially as sources of information when planning final status surveys (Section 5.3)
Remedial Action Support Survey	Remedial Action Data Life Cycle	Plan Implement Assess Decide	Discusses the purpose and general approach for performing remedial action support surveys, especially as sources of information when planning final status surveys (Section 5.4)
Final Status Survey	Final Status Data Life Cycle	Plan Implement Assess Decide	Provides detailed guidance for planning final status surveys (Chapter 4 and Section 5.5), selecting measurement techniques (Chapter 6, Chapter 7, and Appendix H), and assessing the data collected during final status surveys (Chapter 8 and Chapter 9)

2.4.1 Site Identification

The identification of known, likely, or potential sites is generally easily accomplished, and is typically performed before beginning decommissioning. Any facility preparing to terminate an NRC or agreement state license would be identified as a site. Formerly terminated NRC licenses may also become sites for the EPA Superfund Program. Portions of military bases or DOE facilities may be identified as sites based on records of authorization to possess or handle radioactive materials. In addition, information obtained during the performance of survey activities may identify additional potential radiation sites related to the site being investigated. Information on site identification is provided in Section 3.3.

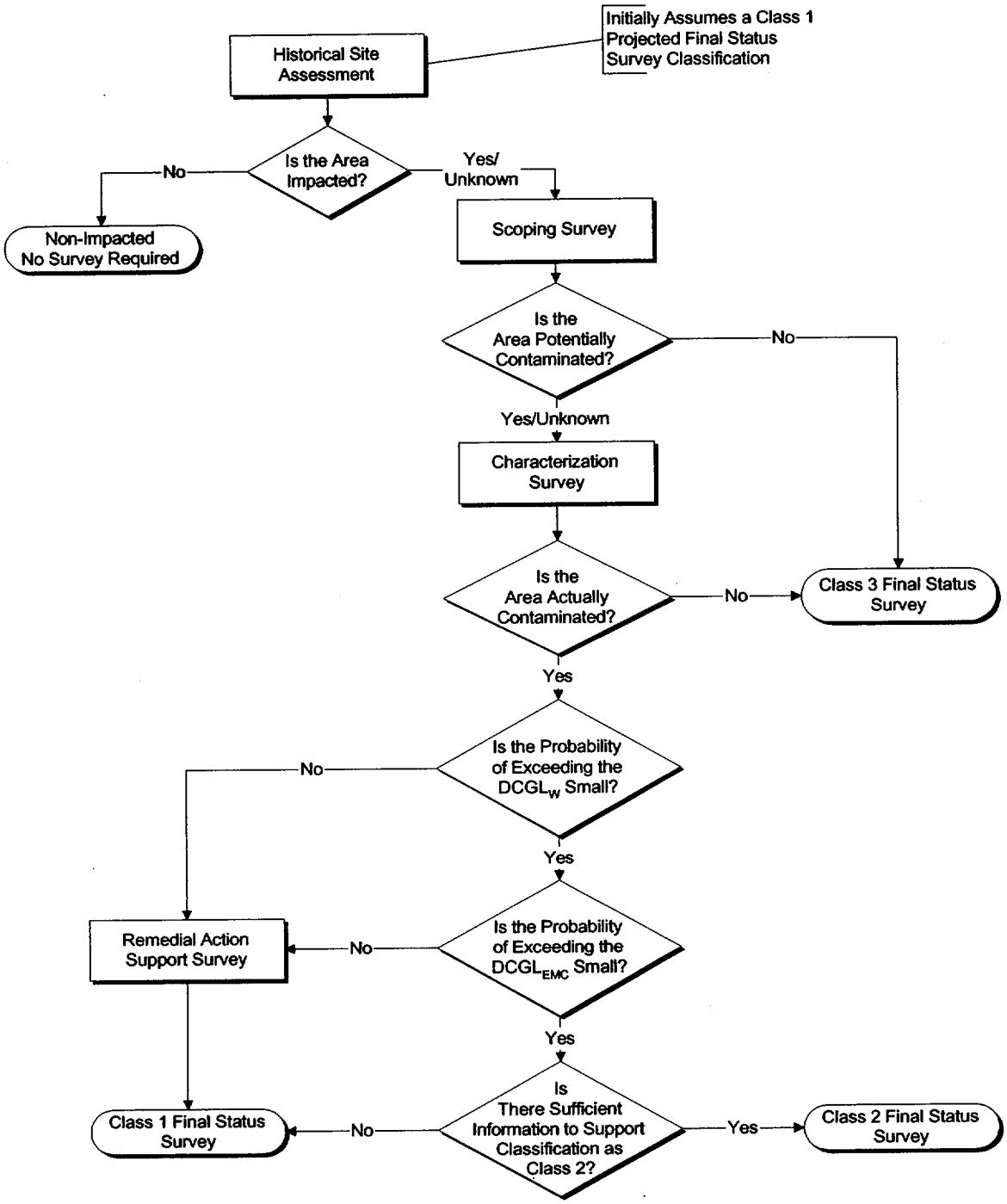


Figure 2.4 The Radiation Survey and Site Investigation Process in Terms of Area Classification

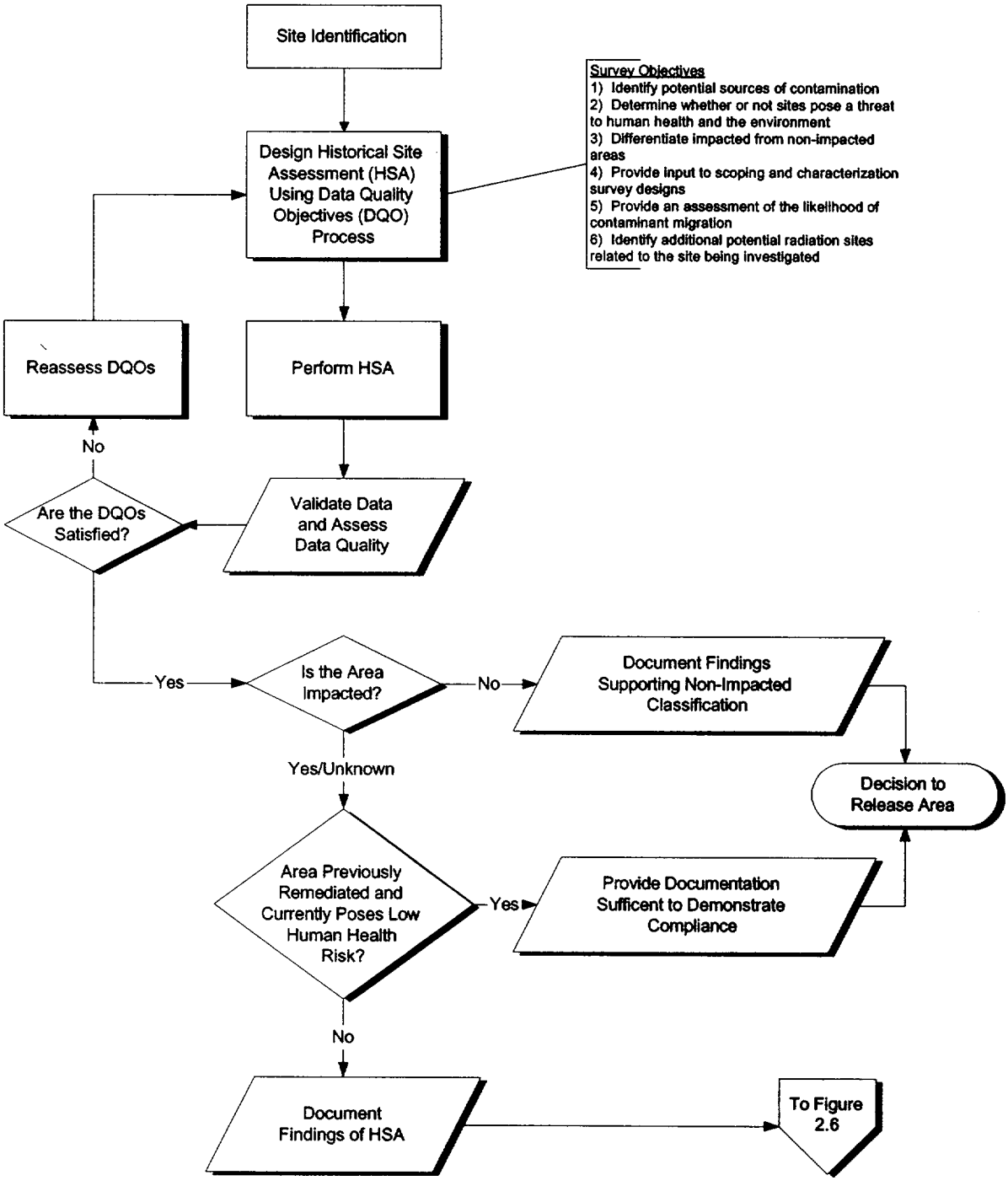


Figure 2.5 The Historical Site Assessment Portion of the Radiation Survey and Site Investigation Process

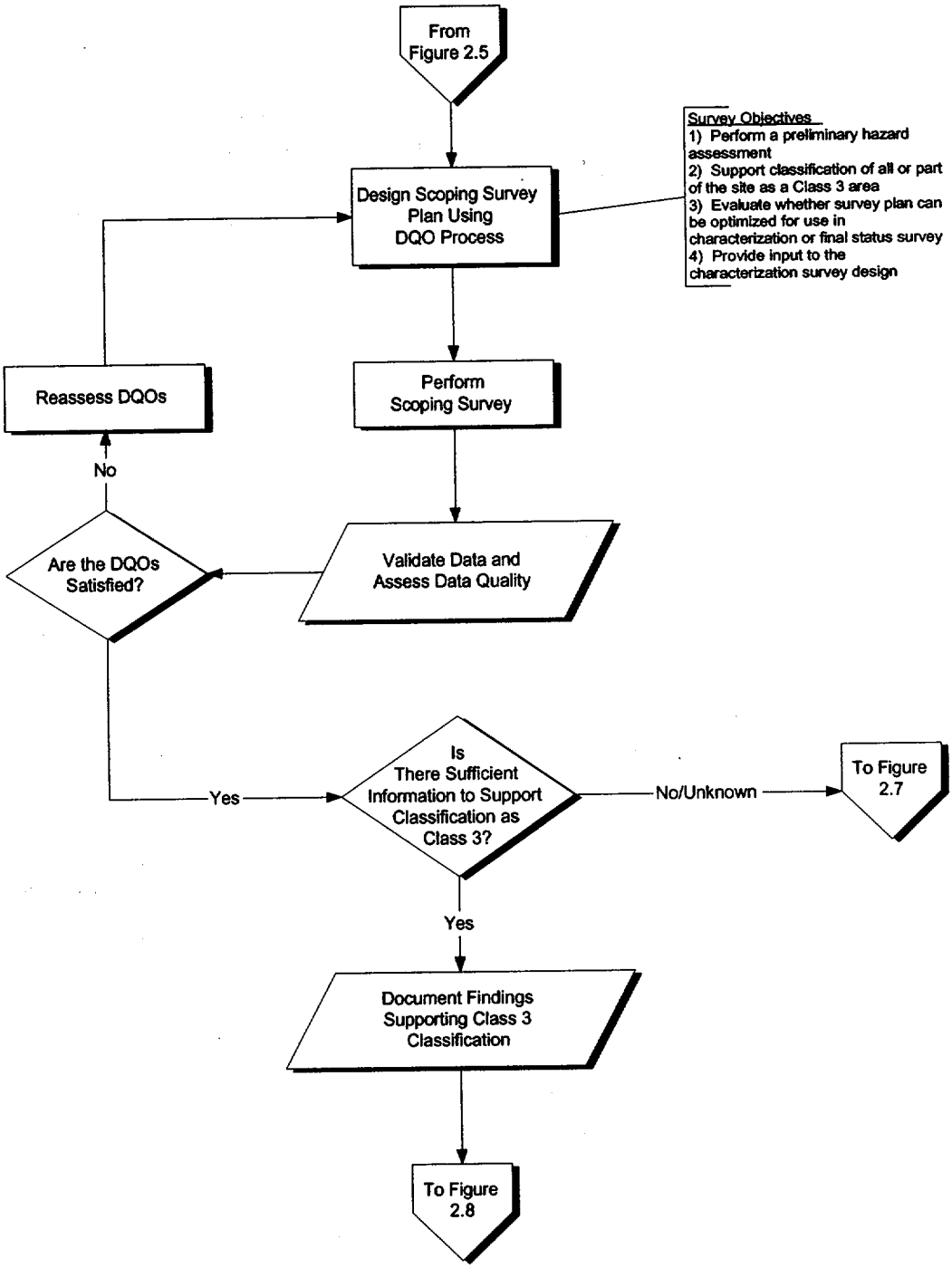
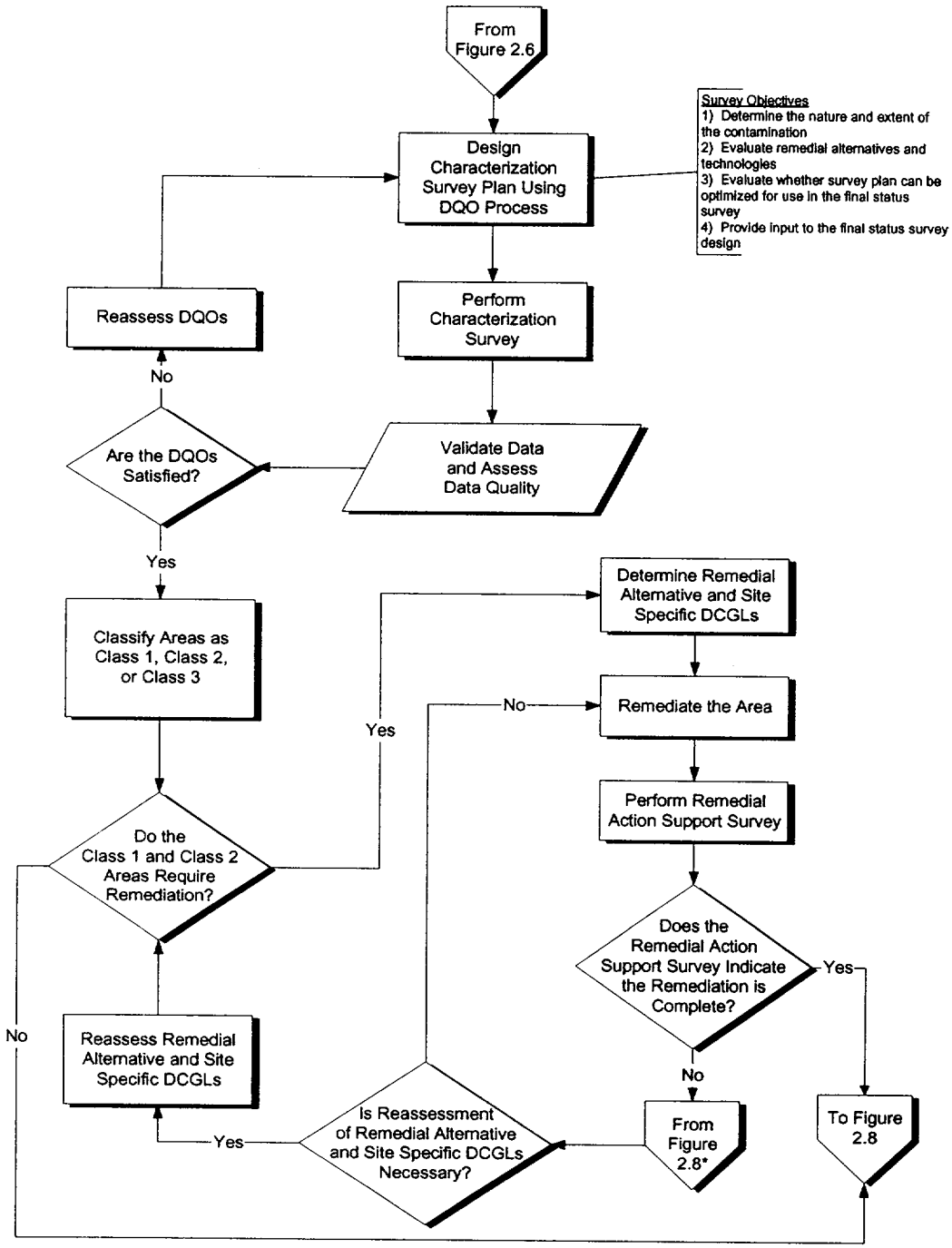
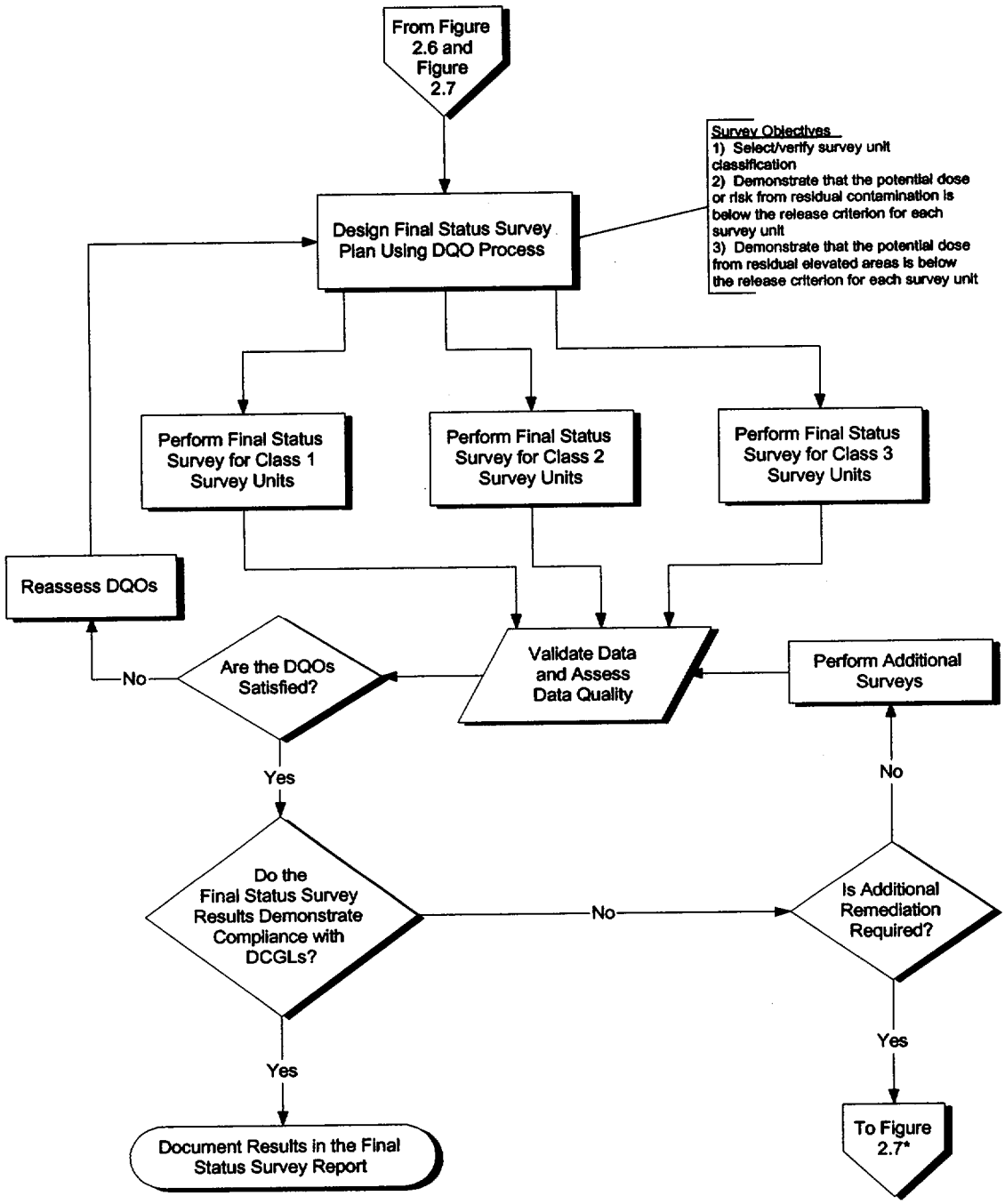


Figure 2.6 The Scoping Survey Portion of the Radiation Survey and Site Investigation Process



* The point where survey units that fail to demonstrate compliance in the final status survey in Figure 2.8 re-enter the process

Figure 2.7 The Characterization and Remedial Action Support Survey Portion of the Radiation Survey and Site Investigation Process



* Connects with the Remedial Action Support Survey portion of the process in Figure 2.7

Figure 2.8 The Final Status Survey Portion of the Radiation Survey and Site Investigation Process

2.4.2 Historical Site Assessment

The primary purpose of the Historical Site Assessment (HSA) is to collect existing information concerning the site and its surroundings.

The primary objectives of the HSA are to:

- identify potential sources of contamination
- determine whether or not sites pose a threat to human health and the environment
- differentiate impacted from non-impacted areas
- provide input to scoping and characterization survey designs
- provide an assessment of the likelihood of contaminant migration
- identify additional potential radiation sites related to the site being investigated

The HSA typically consists of three phases: identification of a candidate site, preliminary investigation of the facility or site, and site visits or inspections. The HSA is followed by an evaluation of the site based on information collected during the HSA.

2.4.3 Scoping Survey

If the data collected during the HSA indicate an area is impacted, a scoping survey could be performed. Scoping surveys provide site-specific information based on limited measurements.

The primary objectives of a scoping survey are to:

- perform a preliminary hazard assessment
- support classification of all or part of the site as a Class 3 area
- evaluate whether the survey plan can be optimized for use in the characterization or final status surveys
- provide data to complete the site prioritization scoring process (CERCLA and RCRA sites only)
- provide input to the characterization survey design if necessary

Scoping surveys are conducted after the HSA is completed and consist of judgment measurements based on the HSA data. If the results of the HSA indicate that an area is Class 3 and no contamination is found, the area may be classified as Class 3 and a Class 3 final status survey is performed. If the scoping survey locates contamination, the area may be considered as Class 1 (or Class 2) for the final status survey and a characterization survey is typically performed. Sufficient information should be collected to identify situations that require immediate radiological attention. For sites where the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) requirements are applicable, the scoping survey should collect sufficient

data to complete the Hazard Ranking System (HRS) scoring process. For sites where the Resource Conservation and Recovery Act (RCRA) requirements are applicable, the scoping survey should collect sufficient data to complete the National Corrective Action Prioritization System (NCAPS) scoring process. Sites that meet the National Contingency Plan (NCP) criteria for a removal should be referred to the Superfund removal program (EPA 1988c). A comparison of MARSSIM guidance to CERCLA and RCRA requirements is provided in Appendix F.

2.4.4 Characterization Survey

If an area could be classified as Class 1 or Class 2 for the final status survey, based on the HSA and scoping survey results, a characterization survey is warranted. The characterization survey is planned based on the HSA and scoping survey results. This type of survey is a detailed radiological environmental characterization of the area.

The primary objectives of a characterization survey are to:

- determine the nature and extent of the contamination
- collect data to support evaluation of remedial alternatives and technologies
- evaluate whether the survey plan can be optimized for use in the final status survey
- support Remedial Investigation/Feasibility Study requirements (CERCLA sites only) or Facility Investigation/Corrective Measures Study requirements (RCRA sites only)
- provide input to the final status survey design

The characterization survey is the most comprehensive of all the survey types and generates the most data. This includes preparing a reference grid, systematic as well as judgment measurements, and surveys of different media (*e.g.*, surface soils, interior and exterior surfaces of buildings). The decision as to which media will be surveyed is a site-specific decision addressed throughout the Radiation Survey and Site Investigation Process.

2.4.5 Remedial Action Support Survey

If an area is adequately characterized and is contaminated above the derived concentration guideline levels (DCGLs), a decontamination plan should be prepared. A remedial action support survey is performed while remediation is being conducted, and guides the cleanup in a real-time mode.

Remedial action support surveys are conducted to:

- support remediation activities
- determine when a site or survey unit is ready for the final status survey

- provide updated estimates of site-specific parameters used for planning the final status survey

This manual does not provide guidance on the routine operational surveys used to support remediation activities. The determination that a survey unit is ready for a final status survey following remediation is an important step in the RSSI Process. In addition, remedial activities result in changes to the distribution of contamination within the survey unit. For most survey units, the site-specific parameters used during final status survey planning (*e.g.*, variability in the radionuclide concentration, probability of small areas of elevated activity) will need to be re-established following remediation. Obtaining updated values for these critical parameters should be considered when planning a remedial action support survey.

2.4.6 Final Status Survey

The final status survey is used to demonstrate compliance with regulations. This type of survey is the major focus of this manual.

The primary objectives of the final status survey are to:

- select/verify survey unit classification
- demonstrate that the potential dose or risk from residual contamination is below the release criterion for each survey unit
- demonstrate that the potential dose or risk from small areas of elevated activity is below the release criterion for each survey unit

The final status survey provides data to demonstrate that all radiological parameters satisfy the established guideline values and conditions.

Although the final status survey is discussed as if it were an activity performed at a single stage of the site investigation process, this does not have to be the case. Data from other surveys conducted during the Radiation Survey and Site Investigation Process—such as scoping, characterization, and remedial action support surveys—can provide valuable information for planning a final status survey provided they are of sufficient quality.

Professional judgment and biased sampling are important for locating contamination and characterizing the extent of contamination at a site. However, the MARSSIM focus is on planning the final status survey which utilizes a more systematic approach to sampling. Systematic sampling is based on rules that endeavor to achieve the representativeness in sampling consistent with the application of statistical tests.

2.4.7 Regulatory Agency Confirmation and Verification

The regulatory agency responsible for the site often confirms whether the site is acceptable for release. This confirmation may be accomplished by the agency or an impartial party. Although some actual measurements may be performed, much of the work required for confirmation and verification will involve evaluation and review of documentation and data from survey activities. The evaluation may include site visits to observe survey and measurement procedures or split-sample analyses by the regulatory agency's laboratory. Therefore, accounting for confirmation and verification activities during the planning stages is important to each type of survey. In some cases, post-remedial sampling and analysis may be performed by an impartial party. The review of survey results should include verifying that the data quality objectives are met, reviewing the analytical data used to demonstrate compliance, and verifying that the statistical test results support the decision to release the site. Confirmation and verification are generally ongoing processes throughout the Radiation Survey and Site Investigation (RSSI) Process.

2.5 Demonstrating Compliance With a Dose- or Risk-Based Regulation

MARSSIM presents a process for demonstrating compliance with a dose- or risk-based regulation. The RSSI Process provides flexibility in planning and performing surveys based on site-specific considerations. A dose- or risk-based regulation usually allows one to take into account radionuclide and site-specific differences.

The final status survey is designed to demonstrate compliance with the release criterion. The earlier surveys in the RSSI Process are performed to support decisions and assumptions used in the design of the final status survey. These preliminary surveys (*e.g.*, scoping, characterization) may have other objectives in addition to compliance demonstration that need to be considered during survey planning that are not fully discussed in this manual. For this reason MARSSIM focuses on final status survey design. To allow maximum flexibility in the survey design, MARSSIM provides guidance on designing a survey using the RSSI Process. This allows users with few resources available for planning to develop an acceptable survey design. The rationale for the development of the guidance in MARSSIM is presented in the following sections. Users with available planning resources are encouraged to investigate alternate survey designs for site-specific applications using the information provided in Section 2.6.

2.5.1 The Decision to Use Statistical Tests

The objective of compliance demonstration is to provide some level of confidence that the release criterion is not exceeded. As previously stated, 100% confidence in a decision cannot be proven because the data always contain some uncertainty. The use of statistical methods is necessary to provide a quantitative estimate of the probability that the release criterion is not exceeded at a

particular site. Statistical methods provide for specifying (controlling) the probability of making decision errors and for extrapolating from a set of measurements to the entire site in a scientifically valid fashion (EPA 1994b).

Clearly stating the null hypothesis is necessary before a statistical test can be performed. The null hypothesis recommended for use in MARSSIM is: "The residual radioactivity in the survey unit exceeds the release criterion." This statement directly addresses the issue of compliance demonstration for the regulator and places the burden of proof for demonstrating compliance on the site owner or responsible party. The statistical tests are only applied at sites that were subjected to an Historical Site Assessment (HSA). At this point, the results of the HSA have been reviewed and the site is determined to be impacted based on existing data and professional judgment as described in Chapter 3. An impacted site, by definition, is expected to contain areas of contamination, so this statement of the null hypothesis is reasonable for these sites.

The information needed to perform a statistical test is determined by the assumptions used to develop the test. MARSSIM recommends the use of nonparametric statistical tests because these tests use fewer assumptions, and consequently require less information to verify these assumptions. The tests described in MARSSIM (see Chapter 8) are relatively easy to understand and implement compared to other statistical tests.

Site conditions can also affect the selection of statistical tests. The distribution of contamination is of particular concern at sites with residual radioactivity. Is the contamination distributed uniformly, or is it located in small areas of elevated activity? Is the residual radioactivity present as surface, volumetric, or subsurface contamination? To demonstrate the use of the RSSI Process at radiation sites, MARSSIM addresses only surface soil and building surfaces for the final status survey to demonstrate compliance. This represents a situation that is expected to commonly occur at sites with radioactive contamination, and allows the survey design to take into account the ability to directly measure surface radioactivity using scanning techniques. Other contaminated media may be identified during the HSA or preliminary surveys (*i.e.*, scoping, characterization, remedial action support). If other contaminated media (*e.g.*, subsurface contamination, volumetric contamination of building materials) are identified, methodologies for demonstrating compliance other than those described in this manual may need to be developed or evaluated. Situations where scanning techniques may not be effective (*e.g.*, volumetric or subsurface contamination) are discussed in existing guidance (EPA 1989a, EPA 1994b, EPA 1994d).

2.5.1.1 Small Areas of Elevated Activity

While the development of DCGLs is outside the scope of MARSSIM, this manual assumes that DCGLs will be developed using exposure pathway models which in turn assume a relatively uniform distribution of contamination. While this represents an ideal situation, small areas of elevated activity are a concern at many sites.

MARSSIM addresses the concern for small areas of elevated activity by using a simple comparison to an investigation level as an alternative to statistical methods. Using the elevated measurement comparison (EMC) represents a conservative approach, in that every measurement needs to be below the action level. The investigation level for this comparison is called the $DCGL_{EMC}$, which is the $DCGL_W$ modified to account for the smaller area. This area factor correction (discussed in Section 5.5.2.4) is considered to be a defensible modification because the exposure assumptions (*e.g.*, exposure time and duration) are the same as those used to develop the $DCGL_W$. In the case of multiple areas of elevated activity in a survey unit, a posting plot (discussed in Section 8.2.2.2) or similar representation of the distribution of activity in the survey unit can be used to determine any pattern in the location of these areas.

If elevated levels of residual radioactivity are found in an isolated area, in addition to residual radioactivity distributed relatively uniformly across the survey unit, the unity rule (Section 4.3.3) can be used to ensure that the total dose or risk meets the release criterion. If there is more than one of these areas, a separate term should be included in the calculation for each area of elevated activity. As an alternative to the unity rule, the dose or risk due to the actual residual radioactivity distribution can be calculated if there is an appropriate exposure pathway model available. Note that these considerations generally only apply to Class 1 survey units, since areas of elevated activity should not be present in Class 2 or Class 3 survey units.

2.5.1.2 Relatively Uniform Distribution of Contamination

As discussed previously, the development of a DCGL starts with the assumption of a relatively uniform distribution of contamination. Some variability in the measurements is expected. This is primarily due to a random spatial distribution of contamination and uncertainties in the measurement process. The arithmetic mean of the measurements taken from such a distribution would represent the parameter of interest for demonstrating compliance.

Whether or not the radionuclide of concern is present in background determines the form of the statistical test. The Wilcoxon Rank Sum (WRS) test is recommended for comparisons of survey unit radionuclide concentrations with background. When the radionuclide of concern is not present in background, the Sign test is recommended. Instructions on performing these tests are provided in Section 8.3 and Section 8.4.

The WRS and Sign tests are designed to determine whether or not the level of residual activity uniformly distributed throughout the survey unit exceeds the $DCGL_W$. Since these methods are based on ranks, the results are generally expressed in terms of the median. When the underlying measurement distribution is symmetric, the mean is equal to the median. When the underlying distribution is not symmetric, these tests are still true tests of the median but only approximate tests of the mean. However, numerous studies show that this is a fairly good approximation (Hardin and Gilbert, 1993). The assumption of symmetry is less restrictive than that of normality because the normal distribution is itself symmetric. If, however, the measurement distribution is skewed to the right, the average will generally be greater than the median. In severe cases, the average may exceed the $DCGL_W$ while the median does not. For this reason, MARSSIM recommends comparing the arithmetic mean of the survey unit data to the $DCGL_W$ as a first step in the interpretation of the data (see Section 8.2.2.1).

The WRS test is a two-sample test that compares the distribution of a set of measurements in a survey unit to that of a set of measurements in a reference area. The test is performed by first adding the value of the $DCGL_W$ to each measurement in the reference area. The combined set of survey unit data and adjusted reference area data are listed, or ranked, in increasing numerical order. If the ranks of the adjusted reference site measurements are significantly higher than the ranks of the survey unit measurements, the survey unit demonstrates compliance with the release criterion.

The Sign test is a one-sample test that compares the distribution of a set of measurements in a survey unit to a fixed value, namely the $DCGL_W$. First, the value for each measurement in the survey unit is subtracted from the $DCGL_W$. The resulting distribution is tested to determine if the center of the distribution is greater than zero. If the adjusted distribution is significantly greater than zero, the survey unit demonstrates compliance with the release criterion.

Guidance on performing the statistical tests and presenting graphical representations of the data is provided in Chapter 8 and Appendix I.

2.5.2 Classification

Classifying a survey unit is crucial to the survey design because this step determines the level of survey effort based on the potential for contamination. Areas are initially classified as impacted or non-impacted based on the results of the HSA. Non-impacted areas have no reasonable potential for residual contamination and require no further evidence to demonstrate compliance with the release criterion. When planning the final status survey, impacted areas may be further divided into survey units. If a survey unit is classified incorrectly, the potential for making decision errors increases. For this reason, all impacted areas are initially assumed to be Class 1. Class 1 areas require the highest level of survey effort because they are known to have contaminant concentrations above the $DCGL_W$, or the contaminant concentrations are unknown. Information

indicating the potential or known contaminant concentration is less than the $DCGL_W$ can be used to support re-classification of an area or survey unit as Class 2 or Class 3.

There is a certain amount of information necessary to demonstrate compliance with the release criterion. The amount of this information that is available and the level of confidence in this information is reflected in the area classification. The initial assumption for affected areas is that none of the necessary information is available. This results in a default Class 1 classification. This corresponds with the statement of the null hypothesis that the survey unit is contaminated, and represents the most efficient case for the regulator. For this reason, the recommendations for a Class 1 final status survey represent the minimal amount of information necessary to demonstrate compliance.

Not all of the information available for an area will have been collected for purposes of compliance demonstration. For example, data are collected during characterization surveys to determine the extent, and not necessarily the amount, of contamination. This does not mean that the data do not meet the objectives of compliance demonstration, but may mean that statistical tests would be of little or no value because the data have not been collected using appropriate protocols or design. Rather than discard potentially valuable information, MARSSIM allows for a qualitative assessment of existing data (Chapter 3). Non-impacted areas represent areas where all of the information necessary to demonstrate compliance is available from existing sources. For these areas, no statistical tests are considered necessary. A classification as Class 2 or Class 3 indicates that some information on describing the potential for contamination is available for that survey unit. The data collection recommendations are modified to account for the information already available, and the statistical tests are performed on the data collected during the final status survey.

As previously stated, the conservative assumption that an area receive a classification of Class 1 is only applied to impacted sites. The HSA (described in Chapter 3) is used to provide an initial classification for the site of impacted or non-impacted based on existing data and professional judgment.

2.5.3 Design Considerations for Small Areas of Elevated Activity

Scanning surveys are typically used to identify small areas of elevated activity. The size of the area of elevated activity that the survey is designed to detect affects the $DCGL_{EMC}$, which in turn determines the ability of a scanning technique to detect these areas. Larger areas have a lower $DCGL_{EMC}$ and are more difficult to detect than smaller areas.

The percentage of the survey unit to be covered by scans is also an important consideration. 100% coverage means that the entire surface area of the survey unit has been covered by the field of view of the scanning instrument. 100% scanning coverage provides a high level of confidence

that all areas of elevated activity have been identified. If the available information concerning the survey unit provides information demonstrating that areas of elevated activity may not be present, the survey unit may be classified as Class 2 or Class 3. Because there is already some level of confidence that areas of elevated activity are not present, 100% coverage may not be necessary to demonstrate compliance. The scanning survey coverage may be adjusted based on the level of confidence supplied by the existing data. If there is evidence providing a high level of confidence that areas of elevated activity are not present, 10% scanning coverage may meet the objectives of the survey. If the existing information provides a lower level of confidence, the scanning coverage may be adjusted between 10 and 100% based on the level of confidence and the objectives of the survey. A general recommendation is to always err to minimize the decision error. In general, scanning the entire survey unit is less expensive than finding areas of elevated activity later in the survey process. Finding such areas will lead to performing additional surveys due to survey unit misclassification.

Another consideration for scanning surveys is the selection of scanning locations. This is not an issue when 100% of the survey unit is scanned. Whenever less than 100% of the survey unit is scanned, a decision must be made on what areas are scanned. The general recommendation is that when large amounts of the survey unit are scanned (*e.g.*, >50%), the scans should be systematically performed along transects of the survey unit. When smaller amounts of the survey unit are scanned, selecting areas based on professional judgment may be more appropriate and efficient for locating areas of elevated activity (*e.g.*, drains, ducts, piping, ditches). A combination of 100% scanning in portions of the survey unit selected based on professional judgement and less coverage (*e.g.*, 20-50%) for all remaining areas may result in an efficient scanning survey design for some survey units.

2.5.4 Design Considerations for Relatively Uniform Distributions of Contamination

The survey design for areas with relatively uniform distributions of contamination is primarily controlled by classification and the requirements of the statistical test. Again, the recommendations provided for Class 1 survey units are designed to minimize the decision error. Recommendations for Class 2 or Class 3 surveys may be appropriate based on the existing information and the level of confidence associated with this information.

The first consideration is the identification of survey units. The identification of survey units may be accomplished early (*e.g.*, scoping) or late (*e.g.*, final status) in the survey process, but must be accomplished prior to performing a final status survey. Early identification of survey units can help in planning and performing surveys throughout the RSSI Process. Late identification of survey units can prevent misconceptions and problems associated with reclassification of areas based on results of subsequent surveys. The area of an individual survey unit is determined based on the area classification and modeling assumptions used to develop the $DCGL_W$. Identification of survey units is discussed in Section 4.6.

Another consideration is the estimated number of measurements to demonstrate compliance using the statistical tests. Section 5.5.2 describes the calculations used to estimate the number of measurements. These calculations use information that is usually available from planning or from preliminary surveys (*i.e.*, scoping, characterization, remedial action support).

The information needed to perform these calculations is: 1) acceptable values for the probabilities of making Type I (α) or Type II (β) decision errors, 2) the estimates of the measurement variability in the survey unit (σ_s) and the reference area (σ_r) if necessary, and 3) the shift (Δ).

MARSSIM recommends that site-specific values be determined for each of these parameters. To assist the user in selecting site-specific values for decision error rates and Δ, MARSSIM recommends that an initial value be selected and adjusted to develop a survey design that is appropriate for a specific site. An arbitrary initial value of one half the $DCGL_W$ is selected for the lower bound of the gray region. This value is adjusted to provide a relative shift (Δ/σ) value between one and three as described in Section 5.5.2. For decision error rates a value that minimizes the risk of making a decision error is recommended for the initial calculations. The number of measurements can be recalculated using different decision error rates until an optimum survey design is obtained. A prospective power curve (see Appendix D, Section D.6 and Appendix I, Section I.9) that considers the effects of these parameters can be very helpful in designing a survey and considering alternative values for these parameters, and is highly recommended.

To ensure that the desired power is achieved with the statistical test and to account for uncertainties in the estimated values of the measurement variabilities, MARSSIM recommends that the estimated number of measurements calculated using the formulas in Section 5.5.2.2 and 5.5.2.3 be increased by 20%. Insufficient numbers of measurements may result in failure to achieve the DQO for power and result in increased Type II decision errors, where survey units below the release criterion fail to demonstrate compliance.

Once survey units are identified and the number of measurements is determined, measurement locations should be selected. The statistical tests assume that the measurements are taken from random locations within the survey unit. A random survey design is used for Class 3 survey units, and a random starting point for the systematic grid is used for Class 2 and Class 1 survey units.

2.5.5 Developing an Integrated Survey Design

To account for assumptions used to develop the $DCGL_W$ and the realistic possibility of small areas of elevated activity, an integrated survey design should be developed to include all of the design considerations. An integrated survey design combines a scanning survey for areas of elevated

activity with random measurements for relatively uniform distributions of contamination. Table 2.2 presents the recommended conditions for demonstrating compliance for a final status survey based on classification.

Table 2.2 Recommended Conditions for Demonstrating Compliance Based on Survey Unit Classification for a Final Status Survey

Survey Unit Classification		Statistical Test	Elevated Measurement Comparison	Sampling and/or Direct Measurements	Scanning
Impacted	Class 1	Yes	Yes	Systematic	100% Coverage
	Class 2	Yes	Yes	Systematic	10-100% Systematic
	Class 3	Yes	Yes	Random	Judgmental
Non-Impacted		No	No	No	None

Random measurement patterns are used for Class 3 survey units to ensure that the measurements are independent and meet the requirements of the statistical tests. Systematic grids are used for Class 2 survey units because there is an increased probability of small areas of elevated activity. The use of a systematic grid allows the decision maker to draw conclusions about the size of any potential areas of elevated activity based on the area between measurement locations, while the random starting point of the grid provides an unbiased method for determining measurement locations for the statistical tests. Class 1 survey units have the highest potential for small areas of elevated activity, so the areas between measurement locations are adjusted to ensure that these areas can be identified by the scanning survey if the area of elevated activity is not detected by the direct measurements or samples.

The objectives of the scanning surveys are different. Scanning is used to identify locations within the survey unit that exceed the investigation level. These locations are marked and receive additional investigations to determine the concentration, area, and extent of the contamination.

For Class 1 areas, scanning surveys are designed to detect small areas of elevated activity that are not detected by the measurements using the systematic grids. For this reason, the measurement locations and the number of measurements may need to be adjusted based on the sensitivity of the scanning technique (see Section 5.5.2.4). This is also the reason for recommending 100% coverage for the scanning survey.

Scanning surveys in Class 2 areas are also performed primarily to find areas of elevated activity not detected by the measurements using the systematic pattern. However, the measurement

locations are not adjusted based on sensitivity of the scanning technique, and scanning is only performed in portions of the survey unit. The level of scanning effort should be proportional to the potential for finding areas of elevated activity: in Class 2 survey units that have residual radioactivity close to the release criterion a larger portion of the survey unit would be scanned, but for survey units that are closer to background scanning a smaller portion of the survey unit may be appropriate. Class 2 survey units have a lower probability for areas of elevated activity than Class 1 survey units, but some portions of the survey unit may have a higher potential than others. Judgmental scanning surveys would focus on the portions of the survey unit with the highest probability for areas of elevated activity. If the entire survey unit has an equal probability for areas of elevated activity, or the judgmental scans don't cover at least 10% of the area, systematic scans along transects of the survey unit or scanning surveys of randomly selected grid blocks are performed.

Class 3 areas have the lowest potential for areas of elevated activity. For this reason, MARSSIM recommends that scanning surveys be performed in areas of highest potential (*e.g.*, corners, ditches, drains) based on professional judgment. This provides a qualitative level of confidence that no areas of elevated activity were missed by the random measurements or that there were no errors made in the classification of the area.

Note that the DCGL itself is not free of error. The assumptions made in any model used to develop DCGLs for a site should be examined carefully. The results of this examination should determine if the use of site-specific parameters result in large changes in the DCGLs, or whether a site-specific model should be developed to obtain DCGLs more relevant to the exposure conditions at the site. Appendix D, Section D.6 provides additional information about the uncertainty associated with the DCGL and other considerations for developing an integrated survey design using the DQO Process.

2.6 Flexibility in Applying MARSSIM Guidance

Section 2.5 describes an example that applies the performance-based guidance presented in Section 2.3 and Section 2.4 to design a survey for a site with specific characteristics (*i.e.*, surface soil and building surface contamination). Obviously this design cannot be uniformly applied at every site with radioactive contamination, so flexibility has been provided in the form of performance-based guidance. This guidance encourages the user to develop a site-specific survey design to account for site-specific characteristics. It is expected that most users will adopt the portions of the MARSSIM guidance that apply to their site. In addition, changes to the overall survey design that account for site-specific differences would be presented as part of the survey plan. The plan should also demonstrate that the extrapolation from measurements performed at specific locations to the entire site or survey unit is performed in a technically defensible manner.

Where Section 2.5 describes the development of a generic survey design that will be applicable at most radiation sites, this section describes the flexibility available within the MARSSIM for designing a site-specific survey design. Alternate methods for accomplishing the demonstration of compliance are briefly described and references for obtaining additional information on these alternate methods are provided.

2.6.1 Alternate Statistical Methods

MARSSIM encourages the use of statistics to provide a quantitative estimate of the probability that the release criterion is not exceeded at a site. While it is unlikely that any site will be able to demonstrate compliance with a dose- or risk-based regulation without at least considering the use of statistics, MARSSIM recognizes that the use of statistical tests may not always provide the most effective method for demonstrating compliance. For example, MARSSIM recommends a simple comparison to an investigation level to evaluate the presence of small areas of elevated activity in place of complicated statistical tests. At some sites a simple comparison of each measurement result to the $DCGL_W$, to demonstrate that all the measurement results are below the release criterion, may be more effective than statistical tests for the overall demonstration of compliance with the regulation provided an adequate number of measurements are performed.

MARSSIM recommends the use of nonparametric statistical tests for evaluating environmental data. There are two reasons for this recommendation: 1) environmental data is usually not normally distributed, and 2) there are often a significant number of qualitative survey results (*e.g.*, less than MDC). Either one of these conditions means that parametric statistical tests may not be appropriate. If one can demonstrate that the data are normally distributed and that there are a sufficient number of results to support a decision concerning the survey unit, parametric tests will generally provide higher power (or require fewer measurements to support a decision concerning the survey unit). The tests to demonstrate that the data are normally distributed generally require more measurements than the nonparametric tests. EPA provides guidance on selecting and performing statistical tests to demonstrate that data are normally distributed (EPA 1996a). Guidance is also available for performing parametric statistical tests (NRC 1992, EPA 1989a, EPA 1994b, EPA 1996a).

There are a wide variety of statistical tests designed for use in specific situations. These tests may be preferable to the generic statistical tests recommended in MARSSIM when the underlying assumptions for these tests can be verified. Table 2.3 lists several examples of statistical tests that may be considered for use at individual sites or survey units. A brief description of the tests and references for obtaining additional information on these tests are also listed in the table. Applying these tests may require consultation with a statistician.

Table 2.3 Examples of Alternate Statistical Tests

Alternate Tests	Probability Model Assumed	Type of Test	Reference	Advantages	Disadvantages
Alternate 1-Sample Tests (no reference area measurements)					
Student's t Test	Normal	Parametric test for H_o: Mean < L	*Guidance for Data Quality Assessment,* EPA QA/G-9, p. 3.2-2.	Appropriate if data appears to be normally distributed and symmetric.	Relies on a non-robust estimator for μ and σ. Sensitive to outliers and departures from normality.
t Test Applied To Logarithms	Lognormal	Parametric test for H_o: Median < L	*Guidance for Data Quality Assessment,* EPA QA/G-9, p. 3.2-2	This is a well- known and easy-to-apply test. Useful for a quick summary of the situation if the data is skewed to right.	Relies on a non-robust estimator for σ. Sensitive to outliers and departures from lognormality.
Minimum Variance Unbiased Estimator For Lognormal Mean	Lognormal	Parametric estimates for mean and variance of lognormal distribution	Gilbert, *Statistical Methods for Environmental Pollution Monitoring,* p. 164, 1987.	A good parametric test to use if the data is lognormal.	Inappropriate if the data is not lognormal.
Chen Test	Skewed to right, including Lognormal	Parametric test for H_o: Mean > 0	*Journal of the American Statistical Association (90),* p.767, 1995.	A good parametric test to use if the data is lognormal.	Applicable only for testing H_o: "survey unit is clean." Survey unit must be significantly greater than 0 to fail. Inappropriate if the data is not skewed to the right.

Table 2.3 (continued)

Alternative Tests	Probability Model Assumed	Type of Test	Reference	Advantages	Disadvantages
Alternate 1-Samples Tests (no reference area measurements)					
Bayesian Approaches	Varies, but a family of probability distributions must be selected.	Parametric test for H_o: Mean < L	DeGroot, *Optimal Statistical Decisions*, p. 157, 1970.	Permits use of subjective "expert judgment" in interpretation of data.	Decisions based on expert judgment may be difficult to explain and defend.
Bootstrap	No restriction	Nonparametric. Uses resampling methods to estimate sampling variance.	Hall, *Annals of Statistics (22)*, p. 2011-2030, 1994.	Avoids assumptions concerning the type of distribution.	Computer intensive analysis required. Accuracy of the results can be difficult to assess.
Lognormal Confidence Intervals Using Bootstrap	Lognormal	Uses resampling methods to estimate one-sided confidence interval for lognormal mean.	Angus, *The Statistician (43)*, p. 395, 1994.	Nonparametric method applied within a parametric lognormal model.	Computer intensive analysis required. Accuracy of the results can be difficult to assess.

Table 2.3 (continued)

Alternative Tests	Probability Model Assumed	Type of Test	Reference	Advantages	Disadvantages
Alternate 2-Sample Tests (reference area measurements are required)					
Student's t Test	Symmetric, normal	Parametric test for difference in means H_o: $\mu_x < \mu_y$	*Guidance for Data Quality Assessment,* EPA QA/G-9, p. 3.3-2	Easy to apply. Performance for non-normal data is acceptable.	Relies on a non-robust estimator for σ, therefore test results are sensitive to outliers.
Mann-Whitney Test	No restrictions	Nonparametric test difference in location H_o: $\mu_x < \mu_y$	Hollander and Wolfe, *Nonparametric Statistical Methods,* p. 71, 1973.	Equivalent to the WRS test, but used less often. Similar to resampling, because test is based on set of all possible differences between the two data sets.	Assumes that the only difference between the test and reference areas is a shift in location.
Kolmogorov-Smirnov	No restrictions	Nonparametric test for any difference between the 2 distributions	Hollander and Wolfe, *Nonparametric Statistical Methods,* p. 219, 1973.	A robust test for equality of two sample distributions against all alternatives.	May reject because variance is high, although mean is in compliance.
Bayesian Approaches	Varies, but a family of probability distributions must be selected	Parametric tests for difference in means or difference in variance.	Box and Tiao, *Bayesian Inference in Statistical Analysis*, Chapter 2, 1973.	Permits use of "expert judgment" in the interpretation of data.	Decisions based on expert judgement may be difficult to explain and defend.

Table 2.3 (continued)

Alternative Tests	Probability Model Assumed	Type of Test	Reference	Advantages	Disadvantages
Alternate 2-Sample Tests (reference area measurements are required)					
2-Sample Quantile Test	No restrictions	Nonparametric test for difference in shape and location.	EPA, *Methods for Evaluating the Attainment of Cleanup Standards, Vol. 3*, p. 7.1, 1992.	Will detect if survey unit distribution exceeds reference distribution in the upper quantiles.	Applicable only for testing H_o: "survey unit is clean." Survey unit must be significantly greater than 0 to fail.
Simultaneous WRS and Quantile Test	No restrictions	Nonparametric test for difference in shape and location.	EPA, *Methods for Evaluating the Attainment of Cleanup Standards, Vol. 3*, p. 7.17, 1992.	Additional level of protection provided by using two tests. Has advantages of both tests.	Cannot be combined with the WRS test that uses H_o: "survey unit is not clean." Should only be combined with WRS test for H_o: "survey unit is clean."
Bootstrap and Other Resampling Methods	No restrictions	Nonparametric. Uses resampling methods to estimate sampling variance.	Hall, *Annals of Statistics (22)*, p. 2011, 1994.	Avoids assumptions concerning the type of distribution. Generates informative resampling distributions for graphing.	Computer intensive analysis required.
Alternate to Statistical Tests					
Decision Theory	No restrictions	Incorporates loss function in the decision theory approach.	DOE, *Statistical and Cost-Benefit Enhancements to the DQO Process for Characterization Decisions*, 1996.	Combines elements of cost-benefit analysis and risk assessment into the planning process.	Limited experience in applying the method to compliance demonstration and decommissioning. Computer intensive analysis required.

2.6.2 Alternate Null Hypothesis

The selection of the null hypothesis in MARSSIM is designed to be protective of human health and the environment as well as consistent with current methods used for demonstrating compliance with regulations. MARSSIM also acknowledges that site-specific conditions (*e.g.*, high variability in background, lack of measurement techniques with appropriate detection sensitivity) may preclude the use of the null hypothesis that the survey unit is assumed to be contaminated. Similarly, a different null hypothesis and methodology could be used for different survey units (*e.g.*, Class 3 survey units). NUREG 1505 (NRC 1997b) provides guidance on determining when background variability might be an issue, designing surveys based on the null hypothesis that the survey unit concentration is indistinguishable from the concentration in the reference area, and performing statistical tests to demonstrate that the survey unit is indistinguishable from background.

2.6.3 Integrating MARSSIM with Other Survey Designs

2.6.3.1 Accelerated Cleanup Models

There are a number of approaches designed to expedite site cleanups. These approaches can save time and resources by reducing sampling, preventing duplication of effort, and reducing inactive time periods between steps in a cleanup process. Although Section 2.4 describes the RSSI Process recommended in MARSSIM as one with six principal steps, MARSSIM is not intented to be a serial process that would slow site cleanups. Rather, MARSSIM supports existing programs and encourages approaches to expedite site cleanups. Part of the significant emphasis on planning in MARSSIM is meant to promote saving time and resources.

There are many examples of accelerated cleanup approaches. The Superfund Accelerated Cleanup Model (SACM), which includes a module called integrated site assessment, has as its objectives increased efficiency and shorter response times (EPA 1992f, EPA 1993c, EPA 1997b).

Sandia National Laboratories (SNL) uses the Observational Approach. This approach uses an iterative process of sample collection and real-time data evaluation to characterize a site. This process allows early field results to guide later data collection in the field. Data collection is limited to only that required for selecting a unique remedy for a site.[5]

At DOE's Hanford Site, the parties to the Tri-Party Agreement negotiated a method to implement the CERCLA process in order to 1) accelerate the assessment phase, and 2) coordinate RCRA

[5] Information on the Observational Approach recommended by Sandia National Laboratories is available on the internet at http://www.em.doe.gov/tie/strechar.html.

and CERCLA requirements whenever possible, thereby resulting in cost savings. The Hanford Past Practice Strategy (HPPS) was developed in 1991 to accelerate decisionmaking and initiation of remediation through activities that include maximizing the use of existing data consistent with data quality objectives.[6]

The adaptive sampling programs at the Environmental Assessment Division (EAD) of Argonne National Laboratory quantitatively fuse soft data (for example, historical records, aerial photos, nonintrusive geophysical data) with hard sampling results to estimate contaminant extent, measure the uncertainty associated with these estimates, determine the benefits from collecting additional samples, and assist in siting new sample locations to maximize the information gained.[7]

2.6.3.2 Superfund Soil Screening Guidance

The goal of the Soil Screening Guidance (EPA 1996b, EPA 1996c) is to help standardize and accelerate the evaluation and cleanup of contaminated soils at sites on the National Priorities List (NPL) designated for future residential land use. The guidance provides a methodology for calculating risk-based, site-specific, soil screening levels for chemical contaminants in soil that may be used to identify areas needing further investigation at NPL sites. While the Soil Screening Guidance was not developed for use with radionuclides, the methodology used is comparable to the MARSSIM guidance for demonstrating compliance using DCGLs. The Soil Screening Guidance assumes that there is a low probability of contamination, and does not account for small areas of elevated activity. These assumptions correlate to a Class 3 area in MARSSIM. Because the Soil Screening Guidance is designed as a screening tool instead of a final demonstration of compliance, the specific values for decision error levels, the bounds of the gray region, and the number and location of measurements are developed to support these objectives. However, MARSSIM guidance can be integrated with the survey design in the Soil Screening Guidance using this guidance as an alternate MARSSIM survey design.

The Soil Screening Guidance survey design is based on collecting samples, so scan surveys and direct measurements are not considered. To reduce analytical costs the survey design recommends compositing samples and provides a statistical test for demonstrating compliance. Compositing samples provides an additional source of uncertainty and prevents the detection of small areas of elevated activity.

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[6] Information on the Hanford Past Practice Strategy is available on the internet at http://www.bhi-erc.com/map/sec5.html.

[7] Information on the Argonne National Laboratory adaptive sampling programs can be obtained on the internet at http://www.ead.anl.gov/~web/newead/prgprj/proj/adaptive/adaptive.html.

3 HISTORICAL SITE ASSESSMENT

3.1 Introduction

The Radiation Survey and Site Investigation (RSSI) Process uses a graded approach that starts with the Historical Site Assessment (HSA) and is later followed by other surveys that lead to the final status survey. The HSA is an investigation to collect existing information describing a site's complete history from the start of site activities to the present time. The necessity for detailed information and amount of effort to conduct an HSA depend on the type of site, associated historical events, regulatory framework, and availability of documented information. For example, some facilities—such as Nuclear Regulatory Commission (NRC) licensees that routinely maintain records throughout their operations—already have HSA information in place. Other facilities, such as Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or Resource Conservation and Recovery Act (RCRA) sites, may initiate a comprehensive search to gather HSA information (also see Appendix F for comparison of Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM), CERCLA, and RCRA). In the former case, the HSA is essentially complete and a review of the following sections ensures that all information sources are incorporated into the overall investigation. In still other cases, where sealed sources or small amounts of radionuclides are described by the HSA, the site may qualify for a simplified decommissioning procedure (see Appendix B).

The HSA

- identifies potential, likely, or known sources of radioactive material and radioactive contamination based on existing or derived information
- identifies sites that need further action as opposed to those posing no threat to human health
- provides an assessment for the likelihood of contaminant migration
- provides information useful to scoping and characterization surveys
- provides initial classification of the site or survey unit[1] as impacted or non-impacted

The HSA may provide information needed to calculate derived concentration guideline levels (DCGLs, initially described in Section 2.2) and furthermore provide information that reveals the magnitude of a site's DCGLs. This information is used for comparing historical data to potential DCGLs and determining the suitability of the existing data as part of the assessment of the site. The HSA also supports emergency response and removal activities within the context of the

[1] Refer to Section 4.6 for a discussion of survey units.

EPA's Superfund program, fulfills public information needs, and furnishes appropriate information about the site early in the Site Investigation process. For a large number of sites (*e.g.* currently licensed facilities), site identification and reconnaissance may not be needed. For certain response activities, such as reports concerning the possible presence of radioactivity, preliminary investigations may consist more of a reconnaissance and a scoping survey in conjunction with efforts to gather historical information.

The HSA is typically described in three sections: identification of a candidate site (Section 3.3), preliminary investigation of the facility or site (Section 3.4), and site reconnaissance (Section 3.5). The reconnaissance however is not a scoping survey. The HSA is followed by an evaluation of the site based on information collected during the HSA.

3.2 Data Quality Objectives

The Data Quality Objectives (DQO) Process assists in directing the planning of data collection activities performed during the HSA. Information gathered during the HSA supports other DQOs when this process is applied to subsequent surveys.

Three HSA-DQO results are expected:

- identifying an individual or a list of planning team members—including the decision maker (DQO Step 1, Appendix D, Section D.1)
- concisely describing the problem (DQO Step 1, Appendix D, Section D.1)
- initially classifying site and survey unit as impacted or non-impacted (DQO Step 4, Appendix D, Section D.4)

Other results may accompany these three, and this added information may be useful in supporting subsequent applications of the DQO process.

The planning team clarifies and defines the DQOs for a site-specific survey. This multidisciplinary team of technical experts offers the greatest potential for solving problems when identifying every important aspect of a survey. Including a stakeholder group representative is an important consideration when assembling this team. Once formed, the team can also consider the role of public participation for this assessment and the possible surveys to follow. The number of team members is directly related to the scope and complexity of the problem. For a small site or simplified situations, planning may be performed by the site owner. For other specific sites (*e.g.*, CERCLA), a regulatory agency representative may be included.

The representative's role facilitates survey planning—without direct participation in survey plan development—by offering comments and information based on past precedent, current guidance, and potential pitfalls. For a large, complex facility, the team may include technical project managers, site managers, scientists, engineers, community and local government representatives, health physicists, statisticians, and regulatory agency representatives. A reasonable effort should be made to include other individuals—that is, specific decision makers or data users—who may use the study findings sometime in the future.

The planning team is generally led by a member who is referred to as the decision maker. This individual is often the person with the most authority over the study and may be responsible for assigning the roles and responsibilities to planning team members. Overall, the decision-making process arrives at final decisions based on the planning team's recommendations.

The problem or situation description provides background information on the fundamental issue to be addressed by the assessment (see EPA 1994a). The following steps may be helpful during DQO development:

- describe the conditions or circumstances regarding the problem or situation and the reason for undertaking the survey
- describe the problem or situation as it is currently understood by briefly summarizing existing information
- conduct literature searches and interviews, and examine past or ongoing studies to ensure that the problem is correctly defined
- if the problem is complex, consider breaking it into more manageable pieces

Section 3.4 provides guidance on gathering existing site data and determining the usability of this data.

The initial classification of the site involves developing a conceptual model based on the existing information collected during the preliminary investigation. Conceptual models describe a site or facility and its environs and present hypotheses regarding the radionuclides for known and potential residual contamination (EPA 1987b, 1987c). The classification of the site is discussed in Section 3.6, Evaluation of Historical Site Assessment Data.

Several results of the DQO Process may be addressed initially during the HSA. This information or decision may be based on limited or incomplete data. As the site assessment progresses and as decisions become more difficult, the iterative nature of the DQO Process allows for re-evaluation of preliminary decisions. This is especially important for classification of sites and survey units where the final classification is not made until the final status survey is planned.

3.3 Site Identification

A site may already be known for its prior use and presence of radioactive materials. Elsewhere, potential radiation sites may be identified through the following:

- records of authorization to possess or handle radioactive materials (*e.g.*, NRC or NRC Agreement State License, DOE facility records, Naval Radioactive Materials Permit, USAF Master Materials License, Army Radiation Authorization, State Authorization for Naturally Occurring and Accelerator Produced Radioactive Material (NARM))
- notification to government Agencies of possible releases of radioactive substances
- citizens filing a petition under section 105(d) of the Superfund Amendments and Reauthorization Act of 1986 (SARA; EPA 1986)
- ground and aerial radiological surveys
- contacts with knowledge of the site
- review of EPA's Environmental Radiation Ambient Monitoring System (ERAMS) database (Appendix G)

Once identified, the name, location, and current legal owner or custodian (where available) of the site should be recorded.

3.4 Preliminary HSA Investigation

This limited-scope investigation serves to collect readily available information concerning the facility or site and its surroundings. The investigation is designed to obtain sufficient information to provide initial classification of the site or survey unit as impacted or non-impacted. Information on the potential distribution of radioactive contamination may be used for classifying each site or survey unit as Class 2 or Class 1 and is useful for planning scoping and characterization surveys.

Table 3.1 provides a set of questions that can be used to assist in the preliminary HSA investigation. Apart from obvious cases (*e.g.*, NRC licensees), this table focuses on characteristics that identify a previously unrecognized or known but undeclared source of potential contamination. Furthermore, these questions may identify confounding factors for selecting reference sites.

Table 3.1 Questions Useful for the Preliminary HSA Investigation

1.	Was the site ever licensed for the manufacture, use, or distribution of radioactive materials under Agreement State Regulations, NRC licenses, or Armed Services permits, or for the use of 91B material?	Indicates a higher probability that the area is impacted.
2.	Did the site ever have permits to dispose of, or incinerate, radioactive material onsite? Is there evidence of such activities?	Evidence of radioactive material disposal indicates a higher probability that the area is impacted.
3.	Has the site ever had deep wells for injection or permits for such?	Indicates a higher probability that the area is impacted.
4.	Did the site ever have permits to perform research with radiation generating devices or radioactive materials except medical or dental x-ray machines?	Research that may have resulted in the release of radioactive materials indicates a higher probability that the area is impacted.
5.	As a part of the site's radioactive materials license were there ever any Soil Moisture Density Gauges (Americium-Beryllium or Plutonium-Beryllium sources), or Radioactive Thickness Monitoring Gauges stored or disposed of onsite?	Leak test records of sealed sources may indicate whether or not a storage area is impacted. Evidence of radioactive material disposal indicates a higher probability that the area is impacted.
6.	Was the site used to create radioactive material(s) by activation?	Indicates a higher probability that the area is impacted.
7.	Were radioactive sources stored at the site?	Leak test records of sealed sources may indicate whether or not a storage area is impacted.
8.	Is there evidence that the site was involved in the Manhattan Project or any Manhattan Engineering District (MED) activities (1942-1946)?	Indicates a higher probability that the area is impacted.
9.	Was the site ever involved in the support of nuclear weapons testing (1945-1962)?	Indicates a higher probability that the area is impacted.
10.	Were any facilities on the site used as a weapons storage area? Was weapons maintenance ever performed at the site?	Indicates a higher probability that the area is impacted.
11.	Was there ever any decontamination, maintenance, or storage of radioactively contaminated ships, vehicles, or planes performed onsite?	Indicates a higher probability that the area is impacted.

Table 3.1 Questions Useful for the Preliminary HSA Investigation (continued)

12.	Is there a record of any aircraft accident at or near the site (*e.g.*, depleted uranium counterbalances, thorium alloys, radium dials)?	May include other considerations such as evidence of radioactive materials that were not recovered.
13.	Was there ever any radiopharmaceutical manufacturing, storage, transfer, or disposal onsite?	Indicates a higher probability that the area is impacted.
14.	Was animal research ever performed at the site?	Evidence that radioactive materials were used for animal research indicates a higher probability that the area is impacted.
15.	Were uranium, thorium, or radium compounds (NORM) used in manufacturing, research, or testing at the site, or were these compounds stored at the site?	Indicates a higher probability that the area is impacted or results in a potential increase in background variability.
16.	Has the site ever been involved in the processing or production of Naturally Occurring Radioactive Material (*e.g.*, radium, fertilizers, phosphorus compounds, vanadium compounds, refractory materials, or precious metals) or mining, milling, processing, or production of uranium?	Indicates a higher probability that the area is impacted or results in a potential increase in background variability.
17.	Were coal or coal products used onsite? If yes, did combustion of these substances leave ash or ash residues onsite? If yes, are runoff or production ponds onsite?	May indicate other considerations such as a potential increase in background variability.
18.	Was there ever any onsite disposal of material known to be high in naturally occurring radioactive materials (*e.g.*, monazite sands used in sandblasting)?	May indicate other considerations such as a potential increase in background variability.
19.	Did the site process pipe from the oil and gas industries?	Indicates a higher probability that the area is impacted or results in a potential increase in background variability.
20.	Is there any reason to expect that the site may be contaminated with radioactive material (other than previously listed)?	See Section 3.6.3.

Appendix G of this document provides a general listing and cross-reference of information sources—each with a brief description of the information contained in each source. The *Site Assessment Information Directory* (EPA 1991e) contains a detailed compilation of data sources, including names, addresses, and telephone numbers of agencies that can provide HSA information.

3.4.1 Existing Radiation Data

Site files, monitoring data, former site evaluation data, Federal, State, or local investigations, or emergency actions may be sources of useful site information. Existing site data may provide specific details about the identity, concentration, and areal distribution of contamination. However, these data should be examined carefully because:

- Previous survey and sampling efforts may not be compatible with HSA objectives or may not be extensive enough to characterize the facility or site fully.

- Measurement protocols and standards may not be known or compatible with HSA objectives (*e.g.*, Quality Assurance/Quality Control (QA/QC) procedures, limited analysis rather than full-spectrum analysis) or may not be extensive enough to characterize the facility or site fully.

- Conditions may have changed since the site was last sampled (*i.e.*, substances may have been released, migration may have spread the contamination, additional waste disposal may have occurred, or decontamination may have been performed).

Existing data can be evaluated using the Data Quality Assessment (DQA) process described in Appendix E. (Also see DOE 1987 and EPA 1980c, 1992a, 1992b, 1996a for additional guidance on evaluating data.)

3.4.1.1 Licenses, Site Permits, and Authorizations

The facility or site radioactive materials license and supporting or associated documents are potential sources of information for licensed facilities. If a license does not exist, there may be a permit or other document that authorized site operations involving radioactivity. These documents may specify the quantities of radioactive material authorized for use at the site, the chemical and physical form of the materials, operations for which the materials are (or were) used, locations of these operations at the facility or site, and total quantities of material used at the site during its operating lifetime.

EPA and State agencies maintain files on a variety of environmental programs. These files may contain permit applications and monitoring results with information on specific waste types and quantities, sources, type of site operations, and operating status of the facility or site. Some of these information sources are listed in Appendix G (*e.g.*, Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS), Resource Conservation and Recovery Information System (RCRIS), Ocean Data Evaluation System (ODES)).

3.4.1.2 Operating Records

Records and other information sources useful for site evaluations include those describing onsite activities; current and past contamination control procedures; and past operations involving demolition, effluent releases, discharge to sewers or onsite septic systems, production of residues, land filling, waste and material storage, pipe and tank leaks, spills and accidental releases, release of facilities or equipment from radiological controls, and onsite or offsite radioactive and hazardous waste disposal. Some records may be or may have been classified for National Security purposes and means should be established to review all pertinent records. Past operations should be summarized in chronological order along with information indicating the type of permits and approvals that authorized these operations. Estimates of the total activity disposed of or released at the site and the physical and chemical form of the radioactive material should also be included. Records on waste disposal, environmental monitoring, site inspection reports, license applications, operational permits, waste disposal material balance and inventory sheets, and purchase orders for radioactive materials are useful—for estimating total activity. Information on accidents, such as fires, flooding, spills, unintentional releases, or leakage, should be collected as potential sources of contamination. Possible areas of localized contamination should be identified.

Site plats or plots, blueprints, drawings, and sketches of structures are especially useful to illustrate the location and layout of buildings on the site. Site photographs, aerial surveys, and maps can help verify the accuracy of these drawings or indicate changes following the time when the drawings were prepared. Processing locations—plus waste streams to and from the site as well as the presence of stockpiles of raw materials and finished product—should be noted on these photographs and maps. Buildings or outdoor processing areas may have been modified or reconfigured such that former processing areas were converted to other uses or configurations. The locations of sewers, pipelines, electric lines, water lines, *etc.*, should also be identified. This information facilitates planning the Site Reconnaissance and subsequent surveys, developing a site conceptual model, and increasing the efficiency of the survey program.

Corporate contract files may also provide useful information during subsequent stages of the Radiation Survey and Site Investigation Process. Older facilities may not have complete operational records, especially for obsolete or discontinued processes. Financial records may also provide information on purchasing and shipping that in turn help to reconstruct a site's operational history.

While operating records can be useful tools during the HSA, the investigator should be careful not to place too much emphasis on this type of data. These records are often incomplete and lack information on substances previously not considered hazardous. Out-of-date blueprints and drawings may not show modifications made during the lifetime of a facility.

3.4.2 Contacts and Interviews

Interviews with current or previous employees are performed to collect first-hand information about the site or facility and to verify or clarify information gathered from existing records. Interviews to collect first-hand information concerning the site or facility are generally conducted early in the data-gathering process. Interviews cover general topics, such as radioactive waste handling procedures. Results of early interviews are used to guide subsequent data collection activities.

Interviews scheduled late in the data gathering process may be especially useful. This activity allows questions to be directed to specific areas of the investigation that need additional information or clarification. Photographs and sketches can be used to assist the interviewer and allow the interviewees to recall information of interest. Conducting interviews onsite where the employees performed their tasks often stimulates memories and facilitates information gathering. In addition to interviewing managers, engineers, and facility workers, interviews may be conducted with laborers and truck drivers to obtain information from their perspective. The investigator should be cautious in the use of interview information. Whenever possible, anecdotal evidence should be assessed for accuracy and results of interviews should be backed up with supporting data. Steps that ensure specific information is properly recorded may include hiring trained investigators and taking affidavits.

3.5 Site Reconnaissance

The objective of the Site Reconnaissance or Site Visit is to gather sufficient information to support a decision regarding further action. Reconnaissance activity is not a risk assessment, a scoping survey, or a study of the full extent of contamination at a facility or site. The reconnaissance offers an opportunity to record information concerning hazardous site conditions as they apply to conducting future survey work. In this regard, information describing physical hazards, structural integrity of buildings, or other conditions, defines potential problems that may impede future work. This section is most applicable to sites with less available information and may not be necessary at other sites having greater amounts of data, such as Nuclear Regulatory Commission (NRC) licensed facilities.

To prepare for the Site Reconnaissance, begin by reviewing what is known about the facility or site and identify data gaps. Given the site-specific conditions, consider whether or not a Site Reconnaissance is necessary and practical. This type of effort may be deemed necessary if a site is abandoned, not easily observed from areas of public access, or discloses little information during file searches. These same circumstances may also make a Site Reconnaissance risky for health and safety reasons—in view of the many unknowns—and may make entry difficult. This investigative step may be practical, but less critical, for active facilities whose operators grant

access and provide requested information. Remember to arrange for proper site access and prepare an appropriate health and safety plan, if required, before initiating the Site Reconnaissance.

Investigators should acquire signed consent forms from the site or equipment owner to gain access to the property to conduct the reconnaissance. Investigators are to determine if State and Federal officials, and local individuals, should be notified of the reconnaissance schedule. If needed, local officials should arrange for public notification. Guidance on obtaining access to sites can be found in *Entry and Continued Access Under CERCLA* (EPA 1987d).

A study plan should be prepared before the Site Reconnaissance to anticipate every reconnaissance activity and identify specific information to be gathered. This plan should incorporate a survey of the site's surroundings and provide details for activities that verify or identify the location of: nearby residents, worker populations, drinking water or irrigation wells, foods, and other site environs information.

Preparing for the Site Reconnaissance includes initially gathering necessary materials and equipment. This includes a camera to document site conditions, health and safety monitoring instruments including a radiation detection meter for use during the site visit, and extra copies of topographic maps to mark target locations, water distribution areas, and other important site features. A logbook is critical to keeping a record of field activities and observations as they occur. For documentation purposes MARSSIM recommends that the logbook be completed in waterproof ink, preferably by one individual. Furthermore, each page of the logbook should be signed and dated, including the time of day, after the last entry on the page. Corrections should be documented and approved.

3.6 Evaluation of Historical Site Assessment Data

The main purpose of the Historical Site Assessment (HSA) is to determine the current status of the site or facility, but the data collected may also be used to differentiate sites that need further action from those that pose little or no threat to human health and the environment. This screening process can serve to provide a site disposition recommendation or to recommend additional surveys. Because much of the data collected during HSA activities is qualitative or is analytical data of unknown quality, many decisions regarding a site are the result of professional judgment.

There are three possible recommendations that follow the HSA:

- An emergency action to reduce the risk to human health and the environment—this alternative is applicable to Superfund removal actions, which are discussed in detail by EPA (EPA 1988c).

- The site or area is impacted and further investigation is needed before a decision regarding final disposition can be made. The area may be Class 1, Class 2, or Class 3, and a scoping survey or a characterization survey should be performed. Information collected during the HSA can be very useful in planning these subsequent survey activities.

- The site or area is non-impacted. There is no possibility or an extremely low probability of residual radioactive materials being present at the site. The site or area can be released.

Historical analytical data indicating the presence of contamination in environmental media (surface soil, subsurface soil, surface water, ground water, air, or buildings) can be used to support the hypothesis that radioactive material was released at the facility or site. A decision that the site is contaminated can be made regardless of the quality of the data, its attribution to site operations, or its relationship to background levels. In such cases, analytical indications are sufficient to support the hypothesis—it is not necessary to definitively demonstrate that a problem exists. Conversely, historical analytical data can also be used to support the hypothesis that no release has occurred. However, these data should not be the sole basis for this hypothesis. Using historical analytical data as the principal reason for ruling out the occurrence of contamination forces the data to demonstrate that a problem does not exist.

In most cases it is assumed there will be some level of process knowledge available in addition to historical analytical data. If process knowledge suggests that no residual contamination should be present and the historical analytical data also suggests that no residual contamination is present, the process knowledge provides an additional level of confidence and supports classifying the area as non-impacted. However, if process knowledge suggests no residual contamination should be present but the historical analytical data indicate the presence of residual contamination, the area will probably be considered impacted.

The following sections describe the information recommended for assessing the status of a site. This information is needed to accurately and completely support a site disposition recommendation. If some of the information is not available, it should be identified as a data need for future surveys. Data needs are collected during Step 3 of the Data Quality Objective (DQO) process (Identify Inputs to the Decision) as described in Appendix D, Section D.3. Section 3.6.5 provides information on professional judgment and how it may be applied to the decision making process.

3.6.1 Identify Potential Contaminants

An efficient HSA gathers information sufficient to identify the radionuclides used at the site—including their chemical and physical form. The first step in evaluating HSA data is to estimate the potential for residual contamination by these radionuclides.

Site operations greatly influence the potential for residual contamination (NRC 1992a). An operation that only handled encapsulated sources is expected to have a low potential for contamination—assuming that the integrity of the sources was not compromised. A review of leak-test records for such sources may be adequate to demonstrate the low probability of residual contamination. A chemical manufacturing process facility would likely have contaminated piping, ductwork, and process areas, with a potential for soil contamination where spills, discharges, or leaks occurred. Sites using large quantities of radioactive ores—especially those with outside waste collection and treatment systems—are likely to have contaminated grounds. If loose dispersible materials were stored outside or process ventilation systems were poorly controlled, then windblown surface contamination may be possible.

Consider how long the site was operational. If enough time elapsed since the site discontinued operations, radionuclides with short half-lives may no longer be present in significant quantities. In this case, calculations demonstrating that residual activity could not exceed the DCGL may be sufficient to evaluate the potential residual contaminants at the site. A similar consideration can be made based on knowledge of a contaminant's chemical and physical form. Such a determination relies on records of radionuclide inventories, chemical and physical forms, total amounts of activity in waste shipments, and purchasing records to document and support this decision. However, a number of radionuclides experience significant decay product ingrowth, which should be included when evaluating existing site information.

3.6.2 Identify Potentially Contaminated Areas

Information gathered during the HSA should be used to provide an initial classification of the site areas as impacted or non-impacted.

Impacted areas have a potential for radioactive contamination (based on historical data) or contain known radioactive contamination (based on past or preliminary radiological surveillance). This includes areas where 1) radioactive materials were used and stored; 2) records indicate spills, discharges, or other unusual occurrences that could result in the spread of contamination; and 3) radioactive materials were buried or disposed. Areas immediately surrounding or adjacent to these locations are included in this classification because of the potential for inadvertent spread of contamination.

Non-impacted areas—identified through knowledge of site history or previous survey information—are those areas where there is no reasonable possibility for residual radioactive contamination. The criteria used for this segregation need not be as strict as those used to demonstrate final compliance with the regulations. However, the reasoning for classifying an area as non-impacted should be maintained as a written record. Note that—based on accumulated survey data—an impacted area's classification may change as the RSSI Process progresses.

All potential sources of radioactivity in impacted areas should be identified and their dimensions recorded (in 2 or 3 dimensions—to the extent they can be measured or estimated). Sources can be delineated and characterized through visual inspection during the site reconnaissance, interviews with knowledgeable personnel, and historical information concerning disposal records, waste manifests, and waste sampling data. The HSA should address potential contamination from the site whether it is physically within or outside of site boundaries. This approach describes the site in a larger context, but as noted in Chapter 1, MARSSIM's scope concerns releasing a site and not areas outside a site's boundaries.

3.6.3 Identify Potentially Contaminated Media

The next step in evaluating the data gathered during the HSA is to identify potentially contaminated media at the site. To identify media that may and media that do not contain residual contamination supports both preliminary area classification (Section 4.4) and planning subsequent survey activities.

This section provides guidance on evaluating the likelihood for release of radioactivity into the following environmental media: surface soil, subsurface soil, sediment, surface water, ground water, air, and buildings. While MARSSIM's scope is focused on surface soils and building surfaces, this section makes note of still other media to provide a starting place to identify and address all possible media. The evaluation will result in either a finding of "Suspected Contamination" or "No Suspected Contamination," which may be based on analytical data, professional judgment, or a combination of the two.

Subsequent sections describe the environmental media and pose questions pertinent to each type. Each question is accompanied by a commentary. Carefully consider the questions within the context of the site and the available data. Avoid spending excessive amounts of time answering each question because answers to every question are unlikely to be available at each site. Questions that cannot be answered based on existing data can be used to direct future surveys of the site. Also, keep in mind the numerous differences in site-specific circumstances and that the questions do not identify every characteristic that might apply to a specific site. Additional questions or characteristics identified during a specific site assessment should be included in the HSA report (Section 3.8; EPA 1991f).

3.6.3.1 Surface Soil

Surface soil is the top layer of soil on a site that is available for direct exposure, growing plants, resuspension of particles for inhalation, and mixing from human disturbances. Surface soil may also be defined as the thickness of soil that can be measured using direct measurement or scanning techniques. Typically, this layer is represented as the top 15 cm (6 in.) of soil (40 CFR 192). Surface sources may include gravel fill, waste piles, concrete, or asphalt paving. For many sites

where radioactive materials were used, one first assumes that surface contamination exists and the evaluation is used to identify areas of high and low probability of contamination (Class 1, Class 2 or Class 3 areas).

- Were all radiation sources used at the site encapsulated sources?

A site where only encapsulated sources were used would be expected to have a low potential for contamination. A review of the leak-test records and documentation of encapsulated source location may be adequate for a finding of "No Suspected Contamination."

- Were radiation sources used only in specific areas of the site?

Evidence that radioactive materials were confined to certain areas of the site may be helpful in determining which areas are impacted and which are non-impacted.

- Was surface soil regraded or moved elsewhere for fill or construction purposes?

This helps to identify additional potential radiation sites.

3.6.3.2 Subsurface Soil and Media

Subsurface soil and media are defined as any solid materials not considered to be surface soil. The purpose of these investigations is to locate and define the vertical extent of the potential contamination. Subsurface measurements can be expensive, especially for beta- or alpha-emitting radionuclides. Removing areas from consideration for subsurface measurements or defining areas as non-impacted for subsurface sampling conserves limited resources and focuses the site assessment on areas of concern.

- Are there areas of known or suspected surface soil contamination?

Surface soil contamination can migrate deeper into the soil. Surface soil sources should be evaluated based on radionuclide mobility, soil permeability, and infiltration rate to determine the potential for subsurface contamination. Computer modeling may be helpful for evaluating these types of situations.

- Is there a ground-water plume without an identifiable source?

Contaminated ground water indicates that a source of contamination is present. If no source is identified during the HSA, subsurface contamination is a probable source.

- Is there potential for enhanced mobility of radionuclides in soils?

Radionuclide mobility can be enhanced by the presence of solvents or other volatile chemicals that affect the ion-exchange capacity of soil.

- Is there evidence that the surface has been disturbed?

Recent or previous excavation activities are obvious sources of surface disturbance. Areas with developed plant life (forested or old growth areas) may indicate that the area remained undisturbed during the operating life of the facility. Areas where vegetation is removed during previous excavation activity may be distinct from mature plant growth in adjacent areas. If a site is not purposely replanted, vegetation may appear in a sequence starting with grasses that are later replaced by shrubs and trees. Typically, grasslands recover within a few years, sagebrush or low ground cover appears over decades, while mature forests may take centuries to develop.

- Is there evidence of subsurface disturbance?

Non-intrusive, non-radiological measurement techniques may provide evidence of subsurface disturbance. Magnetometer surveys can identify buried metallic objects, and ground-penetrating radar can identify subsurface anomalies such as trenches or dump sites. Techniques involving special equipment are discussed in Section 6.10.

- Are surface structures present?

Structures constructed at a site—during the operational history of that site—may cover below-ground contamination. Some consideration for contaminants that may exist beneath parking lots, buildings, or other onsite structures may be warranted as part of the investigation. There may be underground piping, drains, sewers, or tanks that caused contamination.

3.6.3.3. Surface Water

Surface waters include streams and rivers, lakes, coastal tidal waters, and oceans. Note that certain ditches and intermittently flowing streams qualify as surface water. The evaluation determines whether radionuclides are likely to migrate to surface waters or their sediments. Where a previous release is not suspected, the potential for future release depends on the distance to surface water and the flood potential at the site. With regard to the two preceding sections, one can also consider an interaction between soil and water in relation to seasonal factors including soil cracking due to freezing, thawing, and dessication that influence the dispersal or infiltration of radionuclides.

- Is surface water nearby?

The proximity of a contaminant to local surface water is essentially determined by runoff and radionuclide migration through the soil. The definition for *nearby* depends on site-specific conditions. If the terrain is flat, precipitation is low, and soils are sandy, nearby may be within several meters. If annual precipitation is high or occasional rainfall events are high, within 1,200 meters (3/4 mile) might be considered nearby. In general, sites need not include the surface water pathway where the overland flow distance to the nearest surface water is more than 3,200 meters (2 miles).

- Is the waste quantity particularly large?

Depending on the physical and chemical form of the waste and its location, *large* is a relative term. A *small* quantity of liquid waste may be of more importance—*i.e.*, a greater risk or hazard—than a *large* quantity of solid waste stored in water tight containers.

- Is the drainage area large?

The drainage area includes the area of the site itself plus the upgradient area that produces runoff flowing over the site. Larger drainage areas generally produce more runoff and increase the potential for surface water contamination.

- Is rainfall heavy?

If the site and surrounding area are flat, a combination of heavy precipitation and low infiltration rate may cause rainwater to pool on the site. Otherwise, these characteristics may contribute to high runoff rates that carry radionuclides overland to surface water. Total annual rainfall exceeding one meter (40 inches), or a once in two-year-24-hour precipitation exceeding five cm (two inches) might be considered "heavy."

Rainfall varies for locations across the continental United States from high (*e.g.*, 89 in./y, Mt. Washington, NH) to low values (*e.g.*, 4.2 in./y, Las Vegas, NV). Precipitation rates will vary during the year at each location due to seasonal and geographic factors. A median value for rainfall within the United States, as found in van der Leeden *et al.* 1990, is about 26 in./y as is observed for Minneapolis, MN.

- Is the infiltration rate low?

Infiltration rates range from very high in gravelly and sandy soils to very low in fine silt and clay soils. Paved sites prevent infiltration and generate runoff.

- Are sources of contamination poorly contained or prone to runoff?

Proper containment which prevents radioactive material from migrating to surface water generally uses engineered structures such as dikes, berms, run-on and runoff control systems, and spill collection and removal systems. Sources prone to releases via runoff include leaks, spills, exposed storage piles, or intentional disposal on the ground surface. Sources not prone to runoff include underground tanks, above-ground tanks, and containers stored in a building.

- Is a runoff route well defined?

A well defined runoff route—along a gully, trench, berm, wall, *etc.*—will more likely contribute to migration to surface water than a poorly defined route. However, a poorly defined route may contribute to dispersion of contamination to a larger area of surface soil.

- Has deposition of waste into surface water been observed?

Indications of this type of activity will appear in records from past practice at a site or from information gathered during personal interviews.

- Is ground water discharge to surface water probable?

The hydrogeology and geographical information of the area around and inside the site may be sufficiently documented to indicate discharge locations.

- Does analytical or circumstantial evidence suggest surface water contamination?

Any condition considered suspicious—and that indicates a potential contamination problem—can be considered circumstantial evidence.

- Is the site prone to flooding?

The Federal Emergency Management Agency (FEMA) publishes flood insurance rate maps that delineate 100-year and 500-year flood plains. Ten-year floodplain maps may also be available. Generally, a site on a 500-year floodplain is not considered prone to flooding.

3.6.3.4 Ground Water

Proper evaluation of ground water includes a general understanding of the local geology and subsurface conditions. Of particular interest is descriptive information relating to subsurface stratigraphy, aquifers, and ground water use.

- Are sources poorly contained?

Proper containment which prevents radioactive material from migrating to ground water generally uses engineered structures such as liners, layers of low permeability soil (*e.g.*, clay), and leachate collection systems.

- Is the source likely to contaminate ground water?

Underground tanks, landfills,[2] surface impoundments and lagoons are examples of sources that are likely to release contaminants that migrate to ground water. Above ground tanks, drummed solid wastes, or sources inside buildings are less likely to contribute to ground-water contamination.

- Is waste quantity particularly large?

Depending on the physical and chemical form of the waste and its location, *large* is a relative term. A *small* quantity of liquid waste may be of more importance—*i.e.*, greater risk or hazard—than a *large* quantity of solid waste stored in water tight containers.

- Is precipitation heavy?

If the site and surrounding area are flat, a combination of heavy precipitation and low infiltration rate may cause rainwater to pool on the site. Otherwise, these characteristics may contribute to high runoff rates that carry radionuclides overland to surface water. Total annual rainfall exceeding one meter (40 in.), or a once in two-year-24-hour precipitation exceeding five cm (two in.) might be considered "heavy."

Rainfall varies for locations across the continental United States from high (*e.g.*, 89 in./y, Mt. Washington, NH) to low values (*e.g.*, 4.2 in./y, Las Vegas, NV). Precipitation rates will vary during the year at each location due to seasonal and geographic factors. A median value for rainfall within the United States, as found in van der Leeden *et al.* 1990, is about 26 in./y as is observed for Minneapolis, MN.

- Is the infiltration rate high?

Infiltration rates range from very high in gravelly and sandy soils to very low in fine silt and clay soils. Unobstructed surface areas are potential candidates for further examination to determine infiltration rates.

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[2] Landfills can affect the geology and hydrogeology of a site and produce heterogeneous conditions. It may be necessary to consult an expert on landfills and the conditions they generate.

- Is the site located in an area of karst terrain?

In karst terrain, ground water moves rapidly through channels caused by dissolution of the rock material (usually limestone) that facilitates migration of contaminants.

- Is the subsurface highly permeable?

Highly permeable soils favor downward movement of water that may transport radioactive materials. Well logs, local geologic literature, or interviews with knowledgeable individuals may help answer this question.

- What is the distance from the surface to an aquifer?

The shallower the source of ground water, the higher the threat of contamination. It is difficult to determine whether an aquifer may be a potential source of drinking water in the future (*e.g.*, next 1,000 years). This generally applies to the shallowest aquifer below the site.

- Are suspected contaminants highly mobile in ground water?

Mobility in ground water can be estimated based on the distribution coefficient (K_d) of the radionuclide. Elements with a high K_d, like thorium (*e.g.*, K_d = 3,200 cm^3/g), are not mobile while elements with a low K_d, like hydrogen (*e.g.*, K_d = 0 cm^3/g), are very mobile. The NRC (NRC 1992b) and Department of Energy (DOE) (Yu, *et al.*, 1993) provide a compilation of K_d values. These values can be influenced by site-specific considerations such that site-specific K_d values need to be evaluated or determined. Also, the mobility of a radionuclide can be enhanced by the presence of a solvent or volatile chemical.

- Does analytical or circumstantial evidence suggest ground water contamination?

Evidence for contamination may appear in current site data; historical, hydrogeological, and geographical information systems records; or as a result of personal interviews.

3.6.3.5 Air

Evaluation of air is different than evaluation of other potentially contaminated media. Air is rarely the source of contamination. Air is evaluated as a pathway for resuspending and dispersing radioactive contamination as well as a contaminated media.

- Were there observations of contaminant releases into the air?

Direct observation of a release to the air might occur where radioactive materials are suspected to be present in particulate form (*e.g.*, mine tailings, waste pile) or adsorbed to particulates (*e.g.*, contaminated soil), and where site conditions favor air transport (*e.g.*, dry, dusty, windy).

- Does analytical or circumstantial evidence suggest a release to the air?

Other evidence for releases to the air might include areas of surface soil contamination that do not appear to be caused by direct deposition or overland migration of radioactive material.

- For radon exposure only, are there elevated amounts of radium (^{226}Ra) in the soil or water that could act as a source of radon in the air?

The source, ^{226}Ra, decays to ^{222}Rn, which is radon gas. Once radon is produced, the gas needs a pathway to escape from its point of origin into the air. Radon is not particularly soluble in water, so this gas is readily released from water sources which are open to air. Soil, however, can retain radon gas until it has decayed (see Section 6.9). The rate that radon is emitted by a solid, *i.e.* radon flux, can be measured directly to evaluate potential sources of radon.

- Is there a prevailing wind and a propensity for windblown transport of contamination?

Information pertaining to geography, ground cover (*e.g.*, amount and types of local vegetation), meteorology (*e.g.*, windspeed at 7 meters above ground level) for and around the site, plus site-specific parameters related to surface soil characteristics enter into calculations used to describe particulate transport. Mean annual windspeed can be obtained from the National Weather Service surface station nearest to the site.

3.6.3.6 Structures

Structures used for storage, maintenance, or processing of radioactive materials are potentially contaminated by these materials. The questions presented in Table 3.1 help to determine if a building might be potentially contaminated. The questions listed in this section are for identifying potentially contaminated structures, or portions of structures, that might not be identified using Table 3.1. Section 4.8.3.1 also presents useful information on identifying structural contamination.

- Were adjacent structures used for storage, maintenance, or processing of radioactive materials?

Adjacent is a relative term for this question. A processing facility with a potential for venting radioactive material to the air could contaminate buildings downwind. A facility with little potential for release outside of the structures handling the material would be less likely to contaminate nearby structures.

- Is a building or its addition or a new structure located on a former radioactive waste burial site or contaminated land?

Comparing past and present photographs or site maps and retrieving building permits or other structural drawings and records in relation to historical operations information will reveal site locations where structures may have been built over buried waste or contaminated land.

- Was the building constructed using contaminated material?

Building materials such as concrete, brick, or cinder block may have been formed using contaminated material.

- Does the potentially non-impacted portion of the building share a drainage system or ventilation system with a potentially contaminated area?

Technical and architectural drawings for site structures along with visual inspections are required to determine if this is a concern in terms of current or past operations.

- Is there evidence that previously identified areas of contamination were remediated by painting or similar methods of immobilizing contaminants?

Removable sources of contamination immobilized by painting may be more difficult to locate, and may need special consideration when planning subsequent surveys.

3.6.4 Develop a Conceptual Model of the Site

Starting with project planning activities, one gathers and analyzes available information to develop a conceptual site model. The model is essentially a site diagram showing locations of known contamination, areas of suspected contamination, types and concentrations of radionuclides in impacted areas, potentially contaminated media, and locations of potential reference (background) areas. The diagram should include the general layout of the site including buildings and property boundaries. When possible, produce three dimensional diagrams. The conceptual site model will be upgraded and modified as information becomes available throughout the RSSI Process. The process of developing this model is also briefly described in Attachment A of EPA 1996b.

The model is used to assess the nature and the extent of contamination, to identify potential contaminant sources, release mechanisms, exposure pathways, human and/or environmental receptors, and to develop exposure scenarios. Further, this model helps to identify data gaps, determine media to be sampled, and assists staff in developing strategies for data collection. Site history and preliminary survey data generally are extremely useful sources of information for developing this model. The conceptual site model should include known and suspected sources of contamination and the types of contaminants and affected media. Such a model can also illustrate known and potential routes of migration and known or potential human and environmental receptors.

The site should be classified or initially divided into similar areas. Classification may be based on the operational history of the site or observations made during the Site Reconnaissance (see Section 3.5.2). After the site is classified using current and past site characteristics, further divide the site or facility based on anticipated future use. This classification can help to a) assign limited resources to areas that are anticipated to be released without restrictions, and b) identify areas with little or no possibility of unrestricted release. Figure 3.1 shows an example of how a site might be classified in this manner. Further classification of a site may be possible based on site disposition recommendations (unrestricted vs. release with passive controls).

3.6.5 Professional Judgment

In some cases, traditional sources of information, data, models, or scientific principles are unavailable, unreliable, conflicting, or too costly or time consuming to obtain. In these instances professional judgment may be the only practical tool available to the investigator. Professional judgment is the expression of opinion, that is documented in written form and based on technical knowledge and professional experience, assumptions, algorithms, and definitions, as stated by an expert in response to technical problems (NRC 1990). For general applications, this type of judgment is a routine part of scientific investigation where knowledge is incomplete. Professional judgment can be used as an independent review of historical data to support decision making during the HSA. Professional judgment should only be used in situations where data are not reasonably obtainable by collection or experimentation.

The process of recruiting professionals should be documented and as unbiased as possible. The credentials of the selected individual or individuals enhance the credibility of the elicitation, and the ability to communicate their reasoning is a primary determinant of the quality of the results. Qualified professionals can be identified by different sources, including the planning team, professional organizations, government agencies, universities, consulting firms, and public interest groups. The selection criteria for the professionals should include potential conflict of interest (economic or personal), evidence of expertise in a required topic, objectiveness, and availability.

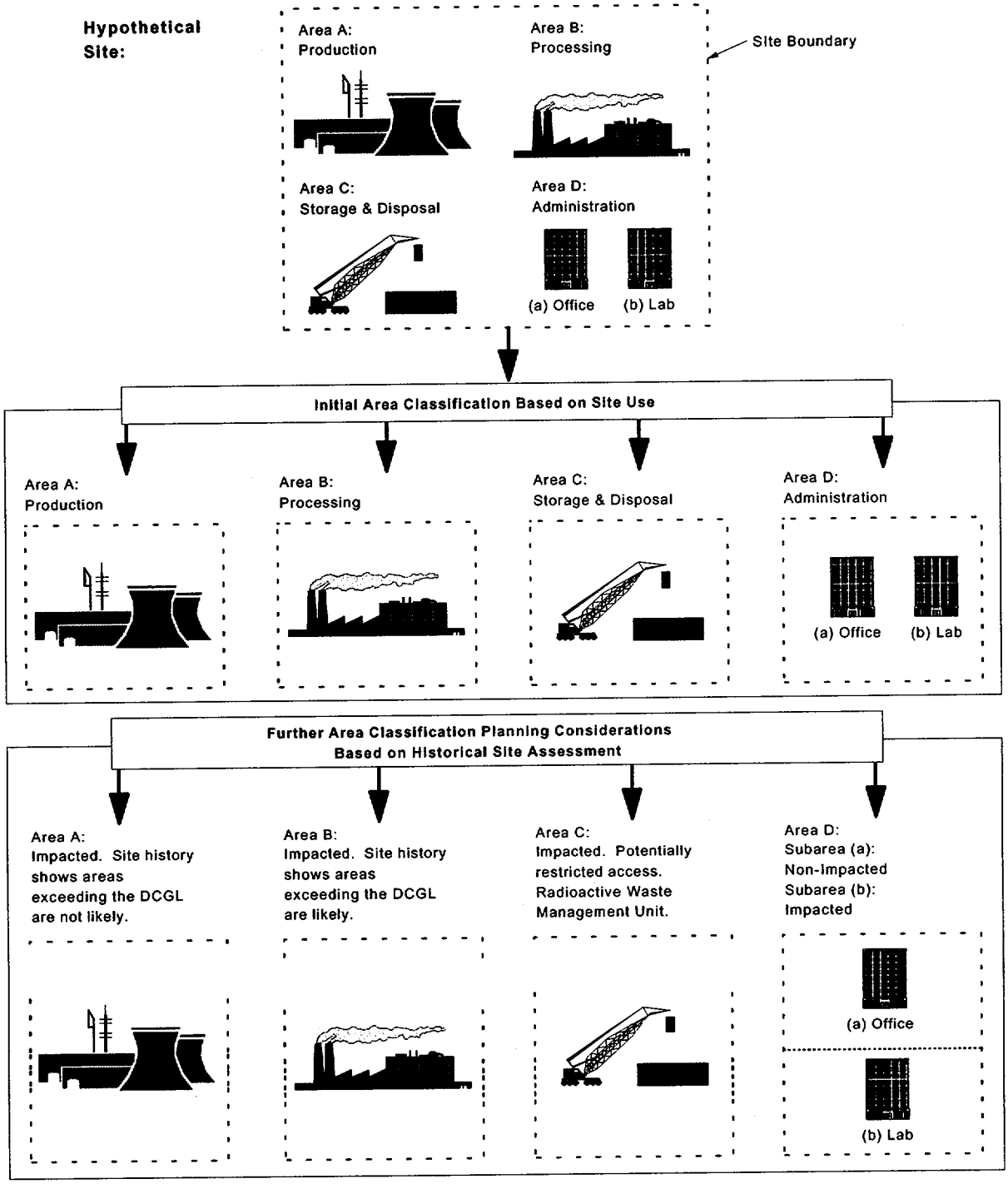


Figure 3.1 Example Showing how a Site Might be Classified Prior to Cleanup Based on the Historical Site Assessment

3.7 Determining the Next Step in the Site Investigation Process

As stated in Section 1.1, the purpose of this manual is to describe a process-oriented approach for demonstrating compliance with the release criterion for residual radioactivity. The highest probability of demonstrating compliance can be obtained by sequentially following each step in the RSSI Process. In some cases, however, performing each step in the process is not practical or necessary. This section provides guidance on how the results of the HSA can be used to determine the next step in the process.

The best method for determining the next step is to review the purpose for each type of survey described in Chapter 5. For example, a scoping survey is performed to provide sufficient information for determining 1) whether present contamination warrants further evaluation and 2) initial estimates of the level of effort for decontamination and preparing a plan for a more detailed survey. If the HSA demonstrates that this information is already available, do not perform a scoping survey. On the other hand, if the information obtained during the HSA is limited, a scoping survey may be necessary to narrow the scope of the characterization survey.

The exception to conducting additional surveys before a final status survey is the use of HSA results to release a site. Generally, the analytical data collected during the HSA are not adequate to statistically demonstrate compliance for impacted areas as described in Chapter 8. This means that the decision to release the site will be based on professional judgment. This determination will ultimately be decided by the responsible regulatory agency.

3.8 Historical Site Assessment Report

A narrative report is generally a useful product for an HSA. Use this report to summarize what is known about the site, what is assumed or inferred, activities conducted during the HSA, and all researched information. Cite a supporting reference for each factual statement given in the report. Attach copies of references (*i.e.*, those not generally available to the public) to the report. The narrative portion of the report should be written in plain English and avoid the use of technical terminology.

To encourage consistency in the content of HSA narratives, both the structure and content of each report should follow the outline shown in Figure 3.2. Additional information not identified in the outline may be requested by the regulatory agency at its discretion. The level of effort to produce the report should reflect the amount of information gathered during the HSA.

3.9 Review of the HSA

The planning team should ensure that someone (a first reviewer) conducts a detailed review of the HSA report for internal consistency and as a quality-control mechanism. A second reviewer with considerable site assessment experience should then examine the entire information package to assure consistency and to provide an independent evaluation of the HSA conclusions. The second reviewer also evaluates the package to determine if special circumstances exist where radioactivity may be present but not identified in the HSA. Both the first reviewer and a second independent reviewer should examine the HSA written products to ensure internal consistency in the report's information, summarized data, and conclusions. The site review ensures that the HSA's recommendations are appropriate.

An important quality assurance objective is to find and correct errors. A significant inconsistency indicating either an error or a flawed conclusion, if undetected, could contribute to an inappropriate recommendation. Identifying such a discrepancy directs the HSA investigator and site reviewers to reexamine and resolve the apparent conflict.

Under some circumstances, experienced investigators may have differing interpretations of site conditions and draw differing conclusions or hypotheses regarding the likelihood of contamination. Any such differences should be resolved during the review. If a reviewer's interpretations contradict those of the HSA investigator, the two should discuss the situation and reach a consensus. This aspect of the review identifies significant points about the site evaluation that may need detailed explanation in the HSA narrative report to fully support the conclusions. Throughout the review, the HSA investigator and site reviewers should keep in mind the need for conservative judgments in the absence of definitive proof to avoid underestimating the presence of contamination, which could lead to an inappropriate HSA recommendation.

1. Glossary of Terms, Acronyms and Abbreviations
2. Executive Summary
3. Purpose of the Historical Site Assessment
4. Property Identification
   - 4.1 Physical Characteristics
     - 4.1.1 Name - CERCLIS ID# (if applicable), owner/operator name, address
     - 4.1.2 Location - street address, city, county, state, geographic coordinates
     - 4.1.3 Topography - USGS 7.5 minute quadrangle or equivalent
     - 4.1.4 Stratigraphy
   - 4.2 Environmental Setting
     - 4.2.1 geology
     - 4.2.2 hydrogeology
     - 4.2.3 hydrology
     - 4.2.4 meteorology
5. Historical Site Assessment Methodology
   - 5.1 Approach and Rationale
   - 5.2 Boundaries of Site
   - 5.3 Documents Reviewed
   - 5.4 Property Inspections
   - 5.5 Personal Interviews
6. History and Current Usage
   - 6.1 History - years of operation, type of facility, description of operations, regulatory involvement; permits & licenses, waste handling procedures
   - 6.2 Current Usage - type of facility, description of operations, probable source types and sizes, description of spills or releases, waste manifests, radionuclide inventories, emergency or removal actions
   - 6.3 Adjacent Land Usage - sensitive areas such as wetlands or preschools
7. Findings
   - 7.1 Potential Contaminants
   - 7.2 Potential Contaminated Areas
     - 7.2.1 Impacted Areas—known and potential
     - 7.2.2 Non-Impacted Areas
   - 7.3 Potential Contaminated Media
   - 7.4 Related Environmental Concerns
8. Conclusions
9. References
10. Appendices
    - A. Conceptual Model and Site Diagram showing Classifications
    - B. List of Documents
    - C. Photo documentation Log
      Original photographs of the site and pertinent site features

Figure 3.2 Example of a Historical Site Assessment Report Format

4 PRELIMINARY SURVEY CONSIDERATIONS

4.1 Introduction

This chapter assists the MARSSIM user in designing a survey plan by presenting areas of consideration common to radiation surveys and site investigations in support of decommissioning. The topics discussed here should be addressed during the planning stages of each survey. Figure 4.1 illustrates the sequence of preliminary activities described in this chapter and their relationship to the survey design process.

Conducting radiological surveys in support of decommissioning serves to answer several basic questions, including:

- Is there residual radioactive contamination present from previous uses?
- What is the character (qualitative and quantitative) of the residual activity?
- Is the average residual activity level below the established derived concentration guideline level?
- Are there small localized areas of residual activity in excess of the investigation level?

The survey methods used to evaluate radiological conditions and develop answers to these questions depend on a number of factors including: contaminants, contaminant distribution, acceptable contaminant levels established by the regulatory agency, future site use, and physical characteristics of the site.

4.2 Decommissioning Criteria

The decommissioning process assures that residual radioactivity will not result in individuals being exposed to unacceptable levels of radiation or radioactive materials. Regulatory agencies establish radiation dose standards based on risk considerations and scientific data relating dose to risk. Residual levels of radioactive material that correspond to allowable radiation dose standards are calculated (derived) by analysis of various pathways and scenarios (direct radiation, inhalation, ingestion, *etc.*) through which exposures could occur. These derived levels, known as derived concentration guideline levels (DCGLs), are presented in terms of surface or mass activity concentrations. DCGLs usually refer to average levels of radiation or radioactivity above appropriate background levels. DCGLs applicable to building or other structural and miscellaneous surfaces are expressed in units of activity per surface area (typically Bq/m^2 or $dpm/100\ cm^2$). When applied to soil and induced activity from neutron irradiation, DCGLs are expressed in units of activity per unit of mass (typically Bq/kg or pCi/g).

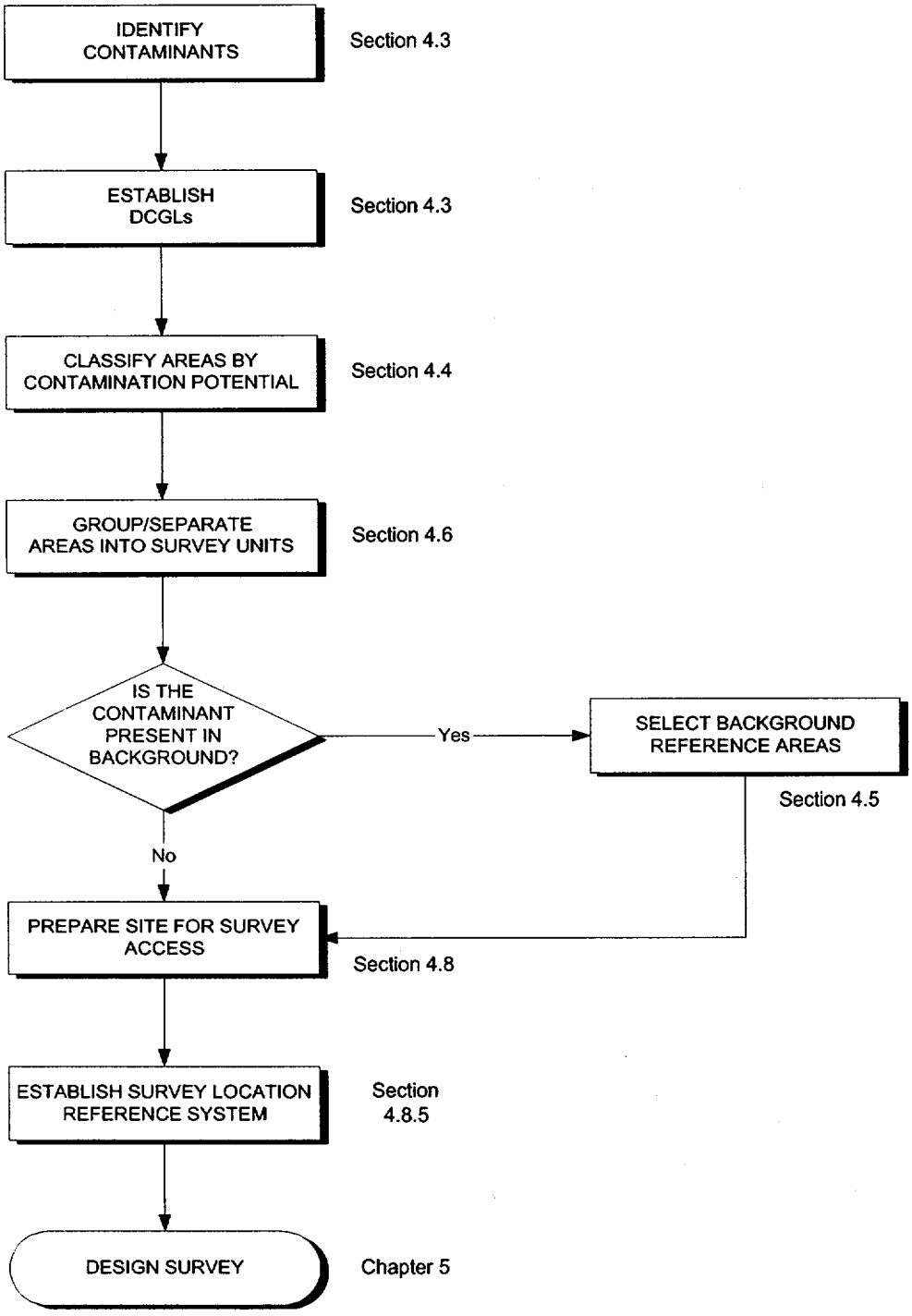


Figure 4.1 Sequence of Preliminary Activities Leading to Survey Design

The $DCGL_W$, based on pathway modeling, is the uniform residual radioactivity concentration level within a survey unit that corresponds to the release criterion (*e.g.*, regulatory limit in terms of dose or risk). Note that for the majority of MARSSIM users, the DCGL will simply be obtained using regulatory agency guidance based on default parameters—other users may elect to perform site-specific pathway modeling to determine DCGLs. In both cases, the DCGL is based on the spatial distribution of the contaminant, and each derivation can produce different values depending on the specific radionuclide distribution and pathway modeling.

In addition to the numerical DCGLs, criteria include conditions for implementing those guideline levels. Conditions applicable to satisfying decommissioning objectives described in Chapter 5 are as follows:

- The uniform residual contamination above background is below the $DCGL_W$.

- Individual measurements or samples, representing small areas of residual radioactivity, do not exceed the $DCGL_{EMC}$ for areas of elevated residual radioactivity. These small areas of residual radioactivity may exceed the $DCGL_W$ established for average residual radioactivity levels in a survey unit, provided these areas of residual radioactivity satisfy the criteria of the responsible regulatory agency.

The manner in which a DCGL is applied should be clearly documented in the survey plans and reports.

4.3 Identify Contaminants and Establish DCGLs

Some objectives of the scoping and characterization surveys, as discussed in Chapter 5, include identifying site contaminants, determining relative ratios of contaminants, and establishing DCGLs and conditions for the contaminants which satisfy the requirements of the responsible agency. Identification of potential radionuclide contaminants at the site is generally performed through laboratory analyses, such as alpha and gamma spectrometry. These analyses are used to determine the relative ratios of the identified contaminants, as well as isotopic ratios for common contaminants like uranium and thorium. This information is essential in establishing and applying the DCGLs for the site. DCGLs provide the goal for essentially all aspects of designing, implementing, and evaluating the final status survey. The DCGLs discussed in this manual are limited to structure surfaces and soil contamination; the user should consult the responsible regulatory agency if it is necessary to establish DCGLs for other environmental media (*e.g.*, ground water, and other water pathways). This section contains information regarding the selection and application of DCGLs.

The development of DCGLs is often an iterative process, where the DCGLs selected or developed early in the Radiation Survey and Site Investigation (RSSI) Process are modified as additional site-specific information is obtained from subsequent surveys. One example of the iterative nature of DCGLs is the development of final cleanup levels in EPA's Superfund program. Soil Screening Levels[1] (SSLs; EPA 1996b, EPA 1996c) are selected or developed at a point early in the process, usually corresponding to the scoping survey in MARSSIM. An SSL can be further developed, based on site-specific information, to become a preliminary remediation goal (PRG; EPA 1991h), usually at a point corresponding to the characterization survey. If the PRG is found to be acceptable during the characterization survey, it is documented as the final cleanup level in the Record of Decision (ROD) for the site. The ROD is typically in place prior to any remedial action, because the remedy is also documented in the ROD. Additional information on the Superfund program can be found in Appendix F.

4.3.1 Direct Application of DCGLs

In the simplest case, the DCGLs may be applied directly to survey data to demonstrate compliance. This involves assessing the surface activity levels and volumetric concentrations of radionuclides and comparing measured values to the appropriate DCGL. For example, consider a site that used only one radionuclide, such as ^{90}Sr throughout its operational lifetime. The default DCGL for ^{90}Sr on building surfaces and in soil may be obtained from the responsible agency. Survey measurements and samples are then compared to the surface and volume activity concentration DCGLs for ^{90}Sr directly to demonstrate compliance. While seemingly straightforward, this approach is not always possible (*e.g.*, when more than one radionuclide is present).

4.3.2 DCGLs and the Use of Surrogate Measurements

For sites with multiple contaminants, it may be possible to measure just one of the contaminants and still demonstrate compliance for all of the contaminants present through the use of surrogate measurements. Both time and resources can be saved if the analysis of one radionuclide is simpler than the analysis of the other. For example, using the measured ^{137}Cs concentration as a surrogate for ^{90}Sr reduces the analytical costs because wet chemistry separations do not have to be performed for ^{90}Sr on every sample. In using one radionuclide to measure the presence of others, a sufficient number of measurements, spatially separated throughout the survey unit, should be made to establish a "consistent" ratio. The number of measurements needed to determine the ratio is selected using the Data Quality Objectives (DQO) Process and based on the chemical, physical, and radiological characteristics of the nuclides and the site. If consistent radionuclide

[1] Soil Screening Levels are currently available for chemical contaminants and are not designed for use at sites with radioactive contamination.

ratios cannot be determined during the Historical Site Assessment (HSA) based on existing information, MARSSIM recommends that one of the objectives of scoping or characterization be a determination of the ratios rather than attempting to determine ratios based on the final status survey. If the ratios are determined using final status survey data, MARSSIM recommends that at least 10% of the measurements (both direct measurements and samples) include analyses for all radionuclides of concern.

In the use of surrogates, it is often difficult to establish a "consistent" ratio between two or more radionuclides. Rather than follow prescriptive guidance on acceptable levels of variability for the surrogate ratio, a more reasonable approach may be to review the data collected to establish the ratio and to use the DQO process to select an appropriate ratio from that data. An example is provided to illustrate the application of surrogate measurements.

Ten soil samples within the survey unit were collected and analyzed for ^{137}Cs and ^{90}Sr to establish a surrogate ratio. The ratios of ^{90}Sr to ^{137}Cs were as follows: 6.6, 5.7, 4.2, 7.9, 3.0, 3.8, 4.1, 4.6, 2.4, and 3.3. An assessment of this example data set results in an average ^{90}Sr to ^{137}Cs surrogate ratio of 4.6, with a standard deviation of 1.7. There are various approaches that may be used to develop a surrogate ratio from this data—but each must consider the variability and level of uncertainty in the data. One may consider the variability in the surrogate ratio by selecting the 95% upper bound of the surrogate ratio (to yield a conservative value of ^{90}Sr from the measured ^{137}Cs), which is 8.0 in this case. Similarly, one may select the most conservative value from the data set (7.9). The DQO process should be used to assess the use of surrogates. The benefit of using the surrogate approach is the reduced cost of not having to perform costly wet chemistry analyses on each sample. This benefit should be considered relative to the difficulty in establishing the surrogate ratio, as well as the potential consequence of unnecessary investigations that result from the error in using a "conservative" surrogate ratio. Selecting a conservative surrogate ratio ensures that potential exposures from individual radionuclides are not underestimated. The surrogate method can only be used with confidence when dealing with the same media in the same surroundings—for example, soil samples with similar physical and geological characteristics. The MARSSIM user will need to consult with the responsible regulatory agency for concurrence on the approach used to determine the surrogate ratio.

Once an appropriate surrogate ratio is determined, one needs to consider how compliance will be demonstrated using surrogate measurements. That is, the user must modify the DCGL of the measured radionuclide to account for the inferred radionuclide. Continuing with the above example, the modified DCGL for ^{137}Cs must be reduced according to the following equation:

$$DCGL_{Cs,\mathrm{mod}} = DCGL_{Cs} \times \frac{DCGL_{Sr}}{[(C_{Sr}/C_{Cs}) \times DCGL_{Cs}] + DCGL_{Sr}} \qquad 4\text{-}1$$

where C_{Sr}/C_{Cs} is the surrogate ratio of ^{90}Sr to ^{137}Cs.

Assuming that the $DCGL_{Sr}$ is 15 Bq/kg, the $DCGL_{Cs}$ is 10 Bq/kg, and the surrogate ratio is 8 (as derived previously), the modified DCGL for ^{137}Cs ($DCGL_{Cs,\,mod}$) can be calculated using Equation 4-1:

$$DCGL_{Cs,mod} = 10 \times \frac{15}{[8 \times 10] + 15} = 1.6\ Bq/kg$$

This modified DCGL is then used for survey design purposes described in Chapter 5.

The potential for shifts or variations in the radionuclide ratios means that the surrogate method should be used with caution. Physical or chemical differences between the radionuclides may produce different migration rates, causing the radionuclides to separate and changing the radionuclide ratios. Remediation activities have a reasonable potential to alter the surrogate ratio established prior to remediation. MARSSIM recommends that when the ratio is established prior to remediation, additional post-remediation samples should be collected to ensure that the data used to establish the ratio are still appropriate and representative of the existing site condition. If these additional post-remediation samples are not consistent with the pre-remediation data, surrogate ratios should be re-established.

Compliance with surface activity DCGLs for radionuclides of a decay series (*e.g.*, thorium and uranium) that emit both alpha and beta radiation may be demonstrated by assessing alpha, beta, or both radiations. However, relying on the use of alpha surface contamination measurements often proves problematic due to the highly variable level of alpha attenuation by rough, porous, and dusty surfaces. Beta measurements typically provide a more accurate assessment of thorium and uranium contamination on most building surfaces because surface conditions cause significantly less attenuation of beta particles than alpha particles. Beta measurements, therefore, may provide a more accurate determination of surface activity than alpha measurements.

The relationship of beta and alpha emissions from decay chains or various enrichments of uranium should be considered when determining the surface activity for comparison with the $DCGL_W$ values. When the initial member of a decay chain has a long half-life, the radioactivity associated with the subsequent members of the series will increase at a rate determined by the individual half-lives until all members of the decay chain are present at activity levels equal to the activity of the parent. This condition is known as secular equilibrium.

Consider an example where the average surface activity $DCGL_W$ for natural thorium is 1,000 Bq/m^2 (600 dpm/100 cm^2), and all of the progeny are in secular equilibrium—that is, for each disintegration of ^{232}Th there are six alpha and four beta particles emitted in the thorium decay

series. Note that in this example, the surface activity $DCGL_W$ of 1,000 Bq/m^2 is assumed to apply to the total activity from all members of the decay chain. In this situation, the corresponding alpha activity $DCGL_W$ should be adjusted to 600 Bq/m^2 (360 dpm/100 cm^2), and the corresponding beta activity $DCGL_W$ to 400 Bq/m^2 (240 dpm/100 cm^2), in order to be equivalent to 1,000 Bq/m^2 of natural thorium surface activity. For a surface activity $DCGL_W$ of 1,000 Bq/m^2, the beta activity $DCGL_W$ is calculated as follows:

$$\frac{\left(\frac{1{,}000\ Bq\ of\ chain}{m^2}\right) \times \left(\frac{4\ \beta}{dis\ of\ Th\text{-}232}\right)}{\frac{10\ Bq\ of\ chain}{1\ Bq\ of\ Th\text{-}232}} = \frac{400\ \beta\ Bq}{m^2} \qquad 4\text{-}2$$

To demonstrate compliance with the beta activity $DCGL_W$ for this example, beta measurements (in cpm) must be converted to activity using a weighted beta efficiency that accounts for the energy and yield of each beta particle. For decay chains that have not achieved secular equilibrium, the relative activities between the different members of the decay chain can be determined as previously discussed for surrogate ratios.

Another example for the use of surrogates involves the measurement of exposure rates, rather than surface or volume activity concentrations, for radionuclides that deliver the majority of their dose through the direct radiation pathway. That is, instead of demonstrating compliance with soil or surface contamination DCGLs derived from the direct radiation pathway, compliance is demonstrated by direct measurement of exposure rates. To implement this surrogate method, Historical Site Assessment (HSA) documentation should provide reasonable assurance that no radioactive materials are buried at the site and that radioactive materials have not seeped into the soil or groundwater. This surrogate approach may still be possible for sites that contain radionuclides that *do not* deliver the majority of their dose through the direct radiation pathway. This requires that a consistent relative ratio for the radionuclides that *do* deliver the majority of their dose through the direct radiation pathway can be established. The appropriate exposure rate limit in this case accounts for the radionuclide(s) that *do not* deliver the majority of their dose to the direct radiation pathway. This is accomplished by determining the fraction of the total activity represented by radionuclide(s) that *do* deliver the majority of their dose through the direct radiation pathway, and weighting the exposure rate limit by this fraction. Note that the considerations for establishing consistent relative ratios discussed above apply to this surrogate approach as well. The responsible regulatory agency should be consulted prior to implementing this surrogate approach.

4.3.3 Use of DCGLs for Sites with Multiple Radionuclides

Typically, each radionuclide DCGL corresponds to the release criterion (*e.g.*, regulatory limit in terms of dose or risk). However, in the presence of multiple radionuclides, the total of the DCGLs for all radionuclides would exceed the release criterion. In this case, the individual DCGLs need to be adjusted to account for the presence of multiple radionuclides contributing to the total dose. One method for adjusting the DCGLs is to modify the assumptions made during exposure pathway modeling to account for multiple radionuclides. The surrogate measurements discussed in the previous section describe another method for adjusting the DCGL to account for multiple radionuclides. Other methods include the use of the unity rule and development of a gross activity DCGL for surface activity to adjust the individual radionuclide DCGLs.

The unity rule, represented in the expression below, is satisfied when radionuclide mixtures yield a combined fractional concentration limit that is less than or equal to one:

$$\frac{C_1}{DCGL_1} + \frac{C_2}{DCGL_2} + \ldots \frac{C_n}{DCGL_n} \leq 1 \qquad 4\text{-}3$$

where

C = concentration
DCGL = guideline value for each individual radionuclide (1, 2, ..., n)

For sites that have a number of significant radionuclides, a higher sensitivity will be needed in the measurement methods as the values of C become smaller. Also, this is likely to affect statistical testing considerations—specifically by increasing the numbers of data points necessary for statistical tests.

4.3.4 Integrated Surface and Soil Contamination DCGLs

Surface contamination DCGLs apply to the total of fixed plus removable surface activity. For cases where the surface contamination is due entirely to one radionuclide, the DCGL for that radionuclide is used for comparison to measurement data (Section 4.3.1).

For situations where multiple radionuclides with their own DCGLs are present, a gross activity DCGL can be developed. This approach enables field measurement of gross activity, rather than determination of individual radionuclide activity, for comparison to the DCGL. The gross activity DCGL for surfaces with multiple radionuclides is calculated as follows:

1. Determine the relative fraction (f) of the total activity contributed by the radionuclide.
2. Obtain the DCGL for each radionuclide present.
3. Substitute the values of f and DCGL in the following equation.

$$Gross\ Activity\ DCGL = \frac{1}{\left(\frac{f_1}{DCGL_1} + \frac{f_2}{DCGL_2} + \ldots \frac{f_n}{DCGL_n} \right)} \qquad 4\text{-}4$$

Example

Assume that 40% of the total surface activity was contributed by a radionuclide with a DCGL of 8,300 Bq/m^2 (5000 dpm/100 cm^2); 40% by a radionuclide with a DCGL of 1,700 Bq/m^2 (1000 dpm/100 cm^2); and 20% by a radionuclide with a DCGL of 830 Bq/m^2 (500 dpm/100 cm^2). Using Equation 4-4,

$$Gross\ Activity\ DCGL = \frac{1}{\frac{0.40}{8,300} + \frac{0.40}{1,700} + \frac{0.20}{830}}$$

$$= 1,900\ Bq/m^2$$

Note that Equation 4-4 may not work for sites exhibiting surface contamination from multiple radionuclides having unknown or highly variable concentrations of radionuclides throughout the site. In these situations, the best approach may be to select the most conservative surface contamination DCGL from the mixture of radionuclides present. If the mixture contains radionuclides that cannot be measured using field survey equipment, laboratory analyses of surface materials may be necessary.

Because gross surface activity measurements are not nuclide-specific, they should be evaluated by the two-sample nonparametric tests described in Chapter 8 to determine if residual contamination meets the release criterion. Therefore, gross surface activity measurements should be performed for both the survey units being evaluated and for background reference areas. The background reference areas for surface activity typically involve building surfaces and construction materials that are considered free of residual radioactivity (see Section 4.5). The total surface activity due to residual contamination should not exceed the gross activity DCGL calculated above.

For soil contamination, it is likely that specific radionuclides, rather than gross activity, will be measured for demonstrating compliance. For radionuclides that are present in natural background, the two-sample nonparametric test described in Section 8.4 should be used to determine if residual soil contamination exceeds the release criterion. The soil contamination due to residual activity should not exceed the DCGL. To account for multiple background radionuclides, the DCGL should be adjusted in a manner similar to the gross activity DCGL described above. For a known mixture of these radionuclides, each having a fixed relative fraction of the total activity, the site-specific DCGLs for each radionuclide may be calculated by first determining the gross activity DCGL and then multiplying that gross DCGL by the respective fractional contribution of each radionuclide. For example, if ^{238}U, ^{226}Ra, and ^{232}Th have DCGLs of 190 Bq/kg (5.0 pCi/g), 93 Bq/kg (2.5 pCi/g), and 37 Bq/kg (1.0 pCi/g) and activity ratios of 40%, 40%, and 20%, respectively, Equation 4-4 can be used to calculate the gross activity DCGL.

$$Gross\ Activity\ DCGL = \frac{1}{\frac{0.40}{190} + \frac{0.40}{93} + \frac{0.20}{37}}$$

$$= 85\ \text{Bq/kg}$$

The adjusted DCGLs for each of the contributory radionuclides, when present in the given activity ratios, are then 34 Bq/kg (0.40 × 85) for ^{238}U, 34 Bq/kg (0.40 × 85) for ^{226}Ra, and 17 Bq/kg (0.20 × 85) for ^{232}Th. Determining gross activity DCGLs to demonstrate compliance enables an evaluation of site conditions based on analysis for only one of the contributory contaminants (surrogate approach), provided the relative ratios of the contaminants do not change.

For situations where the background radionuclides occurring in background have unknown or variable relative concentrations throughout the site, it may be necessary to perform the two-sample nonparametric tests separately for each radionuclide present. The unity rule should be used to determine that the sum of each radionuclide concentration divided by its DCGL is less than or equal to one.

Therefore, at each measurement location calculate the quantity:

$$\frac{C_1}{DCGL_1} + \frac{C_2}{DCGL_2} + \ldots + \frac{C_n}{DCGL_n} \qquad 4\text{-}5$$

where C is the radionuclide concentration.

The values of C are the data to be used in the statistical tests to determine if the average over the survey unit exceeds one.

The same approach applies for radionuclides that are not present in background, with the exception that the one-sample nonparametric statistical test described in Section 8.3 is used in place of the two-sample nonparametric test (see Section 5.5.2.3). Again, for multiple radionuclides either the surrogate approach or the unity rule should be used to demonstrate compliance, if relative ratios are expected to change.

4.4 Classify Areas by Contamination Potential

All areas of the site will not have the same potential for residual contamination and, accordingly, will not need the same level of survey coverage to achieve the established release criteria. The process will be more efficient if the survey is designed so areas with higher potential for contamination (based in part on results of the HSA in Chapter 3) will receive a higher degree of survey effort.

Classification is a critical step in the survey design process. The working hypothesis of MARSSIM is that all impacted areas being evaluated for release have a potential for radioactive contamination above the DCGL. This initial assumption means that all areas are initially considered Class 1 areas unless some basis for reclassification as non-impacted, Class 3, or Class 2 is provided.

Areas that have no reasonable potential for residual contamination do not need any level of survey coverage and are designated as non-impacted areas. These areas have no radiological impact from site operations and are typically identified during the HSA (Chapter 3). Background reference areas are normally selected from non-impacted areas (Section 4.5).

Impacted areas are areas that have some potential for containing contaminated material. They can be subdivided into three classes:

- Class 1 areas: Areas that have, or had prior to remediation, a potential for radioactive contamination (based on site operating history) or known contamination (based on previous radiological surveys). Examples of Class 1 areas include: 1) site areas previously subjected to remedial actions, 2) locations where leaks or spills are known to have occurred, 3) former burial or disposal sites, 4) waste storage sites, and 5) areas with contaminants in discrete solid pieces of material high specific activity. Note that areas containing contamination in excess of the $DCGL_W$ prior to remediation should be classified as Class 1 areas.

- Class 2 areas: These areas have, or had prior to remediation, a potential for radioactive contamination or known contamination, but are not expected to exceed the $DCGL_W$. To justify changing an area's classification from Class 1 to Class 2, the existing data (from the HSA, scoping surveys, or characterization surveys) should provide a high degree of confidence that no individual measurement would exceed the $DCGL_W$. Other justifications for this change in an area's classification may be appropriate based on the outcome of the DQO process. Examples of areas that might be classified as Class 2 for the final status survey include: 1) locations where radioactive materials were present in an unsealed form (*e.g.*, process facilities), 2) potentially contaminated transport routes, 3) areas downwind from stack release points, 4) upper walls and ceilings of some buildings or rooms subjected to airborne radioactivity, 5) areas where low concentrations of radioactive materials were handled, and 6) areas on the perimeter of former contamination control areas.

- Class 3 areas: Any impacted areas that are not expected to contain any residual radioactivity, or are expected to contain levels of residual radioactivity at a small fraction of the $DCGL_W$, based on site operating history and previous radiological surveys. Examples of areas that might be classified as Class 3 include buffer zones around Class 1 or Class 2 areas, and areas with very low potential for residual contamination but insufficient information to justify a non-impacted classification.

Class 1 areas have the greatest potential for contamination and, therefore, receive the highest degree of survey effort, followed by Class 2 and then Class 3 areas.

The criteria used for designating areas as Class 1, 2, or 3 should be described in the final status survey plan. Compliance with the classification criteria should be demonstrated in the final status survey report. A thorough analysis of HSA findings (Chapter 3) and the results of scoping and characterization surveys provide the basis for an area's classification. As a survey progresses, reevaluation of this classification may be necessary based on newly acquired survey data. For example, if contamination is identified in a Class 3 area, an investigation and reevaluation of that area should be performed to determine if the Class 3 area classification is appropriate. Typically, the investigation will result in part or all of the area being reclassified as Class 1 or Class 2. If survey results identify residual contamination in a Class 2 area exceeding the DCGL or suggest that there may be a reasonable potential that contamination is present in excess of the DCGL, an investigation should be initiated to determine if all or part of the area should be reclassified to Class 1. More information on investigations and reclassifications is provided in Section 5.5.3.

4.5 Select Background Reference Areas

Certain radionuclides may also occur at significant levels as part of background in the media of interest (soil, building material, *etc.*). Examples include members of the naturally-occurring uranium, thorium, and actinium series; ^{40}K; ^{14}C; and tritium. ^{137}Cs and other radionuclides are also present in background as a result of nuclear weapons fallout (Wallo, *et al.*, 1994). Establishing background concentrations that describe a distribution of measurement data is necessary to identify and evaluate contributions attributable to site operations. Determining background levels for comparison with the conditions determined in specific survey units entails conducting surveys in one or more reference areas to define the radiological conditions of the site. NUREG-1505 (NRC 1997a) provides additional information on background reference areas.

A site background reference area should have similar physical, chemical, geological, radiological, and biological characteristics as the survey unit being evaluated. Background reference areas are normally selected from non-impacted areas, but are not limited to natural areas undisturbed by human activities. In some situations, a reference area may be associated with the survey unit being evaluated, but cannot be potentially contaminated by site activities. For example, background measurements may be taken from core samples of a building or structure surface, pavement, or asphalt. This option should be discussed with the responsible regulatory agency during survey planning. Generally, reference areas should not be part of the survey unit being evaluated.

Reference areas provide a location for background measurements which are used for comparisons with survey unit data. The radioactivity present in a reference area would be ideally the same as the survey unit had it never been contaminated. If a site includes physical, chemical, geological, radiological, or biological variability that is not represented by a single reference background area, selecting more than one reference area may be necessary.

It may be difficult to find a reference area within an industrial complex for comparison to a survey unit if the radionuclides of potential concern are naturally occurring. Background may vary greatly due to different construction activities that have occurred at the site. Examples of construction activities that change background include: leveling; excavating; adding fill dirt; importing rocks or gravel to stabilize soil or underlay asphalt; manufacturing asphalt with different matrix rock; using different pours of asphalt or concrete in a single survey unit; layering asphalt over concrete; layering different thicknesses of asphalt, concrete, rock, or gravel; and covering or burying old features such as railroad beds or building footings. Background variability may also increase due to the concentration of fallout in low areas of parking lots where runoff water collects and evaporates. Variations in background of a factor of five or more can occur in the space of a few hectares.

There are a number of possible actions to address these concerns. Reviewing and reassessing the selection of reference areas may be necessary. Selecting different reference areas to represent individual survey units is another possibility. More attention may also be needed in selecting survey units and their boundaries with respect to different areas of potential or actual background variability. More detailed scoping or characterization surveys may be needed to better understand background variability. Using radionuclide-specific measurement techniques instead of gross radioactivity measurement techniques may also be necessary. If a background reference area that satisfies the above recommendations is not available, consultation and negotiation with the responsible regulatory agency is recommended. Alternate approaches may include using published studies of radionuclide distributions.

Verifying that a particular background reference area is appropriate for a survey can be accomplished using the techniques described or referenced in Chapter 8. Verification provides assurance that assumptions used to design the survey are appropriate and defensible. This approach can also prevent decision errors that may result from selecting an inappropriate background reference area.

If the radionuclide contaminants of interest do not occur in background, or the background levels are known to be a small fraction of the $DCGL_W$ (*e.g.*, <10%), the survey unit radiological conditions may be compared directly to the specified DCGL and reference area background surveys are not necessary. If the background is not well defined at a site, and the decision maker is willing to accept the increased probability of incorrectly failing to release a survey unit (Type II error), the reference area measurements can be eliminated and a one-sample statistical test performed as described in Section 8.3.

4.6 Identify Survey Units

A survey unit is a physical area consisting of structures or land areas of specified size and shape for which a separate decision will be made as to whether or not that area exceeds the release criterion. This decision is made as a result of the final status survey. As a result, the survey unit is the primary entity for demonstrating compliance with the release criterion.

To facilitate survey design and ensure that the number of survey data points for a specific site are relatively uniformly distributed among areas of similar contamination potential, the site is divided into survey units that share a common history or other characteristics, or are naturally distinguishable from other portions of the site. A site may be divided into survey units at any time before the final status survey. For example, HSA or scoping survey results may provide sufficient justification for partitioning the site into Class 1, 2, or 3 areas. Note, however, that dividing the site into survey units is critical only for the final status survey—scoping, characterization, and remedial action support surveys may be performed without dividing the site into survey units.

A survey unit should not include areas that have different classifications. The survey unit's characteristics should be generally consistent with exposure pathway modeling that is used to convert dose or risk into radionuclide concentrations. For indoor areas classified as Class 1, each room may be designated as a survey unit. Indoor areas may also be subdivided into several survey units of different classification, such as separating floors and lower walls from upper walls and ceilings (and other upper horizontal surfaces) or subdividing a large warehouse based on floor area.

Survey units should be limited in size based on classification, exposure pathway modeling assumptions, and site-specific conditions. The suggested areas for survey units are as follows:

Classification	Suggested Area
Class 1	
Structures	up to 100 m^2 floor area
Land areas	up to 2,000 m^2
Class 2	
Structures	100 to 1,000 m^2
Land areas	2,000 to 10,000 m^2
Class 3	
Structures	no limit
Land areas	no limit

The limitation on survey unit size for Class 1 and Class 2 areas ensures that each area is assigned an adequate number of data points. The rationale for selecting a larger survey unit area should be developed using the DQO Process (Section 2.3) and fully documented. Because the number of data points (determined in Sections 5.5.2.2 or 5.5.2.3) is independent of the survey unit size, disregarding locating small areas of elevated activity, the survey coverage in an area is determined by dividing the fixed number of data points obtained from the statistical tests by the survey unit area. That is, if the statistical test estimates that 20 data points are necessary to demonstrate compliance, then the survey coverage is determined by dividing 20 by the area over which the data points are distributed.

Special considerations may be necessary for survey units with structure surface areas less than 10 m^2 or land areas less than 100 m^2. In this case, the number of data points obtained from the statistical tests is unnecessarily large and not appropriate for smaller survey unit areas. Instead, some specified level of survey effort should be determined based on the DQO process and with the concurrence of the responsible regulatory agency. The data generated from these smaller survey units should be obtained based on judgment, rather than on systematic or random design, and compared individually to the DCGLs.

4.7 Select Instruments and Survey Techniques

Based on the potential radionuclide contaminants, their associated radiations, and the types of residual contamination categories (*e.g.*, soil, structure surfaces) to be evaluated, the detection sensitivities of various instruments and techniques are determined and documented. Instruments should be identified for each of the three types of measurements: 1) scans, 2) direct measurements, and 3) laboratory analysis of samples. In some cases, the same instrument (*e.g.*, sodium iodide detector) or same type of instrument (*e.g.*, gas-flow proportional counter) may be used for performing several types of measurements. Once the instruments are selected, appropriate survey techniques and standard operating procedures (SOPs) should be developed and documented. The survey techniques describe how the instrument will be used to perform the required measurements.

Chapter 6 of this manual, NRC report NUREG-1507 (NRC 1997b), and draft NRC report NUREG-1506 (NRC 1995) discuss the concept of detection sensitivities and provide guidance on determining sensitivities and selecting appropriate measurement methods. Chapter 6 also discusses instruments and survey techniques for scans and direct measurements, while Chapter 7 provides guidance on sampling and laboratory analysis. Appendix H describes typical field and laboratory equipment plus associated cost and instrument sensitivities.

4.7.1 Selection of Instruments

Choose reliable instruments that are suited to the physical and environmental conditions at the site and capable of detecting the radiations of concern to the appropriate minimum detectable concentration (MDC). During survey design, it is generally considered good practice to select a measurement system with an MDC between 10-50% of the DCGL. Sometimes this goal may not be achievable based on site-specific conditions (*e.g.*, best available technology, cost restrictions).

The MDC is calculated based on an hypothesis test for individual measurements (see Section 6.7), and results below the MDC are variable and lead to a high value for σ of the measured values in the survey unit or reference area. This high value for σ can be accounted for using the statistical tests described in Chapter 8 for the final status survey, but a large number of measurements are needed to account for the variability. σ is defined as the standard deviation of the measurements in the survey unit.

Early in decommissioning, during scoping and characterization, low MDCs help in the identification of areas that can be classified as non-impacted or Class 3 areas. These decisions are usually based on fewer numbers of samples, and each measurement is evaluated individually. Using an optimistic estimation of the MDC (see Section 2.3.5) for these surveys may result in the misclassification of a survey unit and cleaning up an uncontaminated area or performing a final status survey in a contaminated area. Selecting a measurement technique with a well defined

MDC or a conservative estimate of the MDC ensures the usefulness of the data for making decisions for planning the final status survey. For these reasons, MARSSIM recommends that a realistic or conservative estimate of the MDC be used instead of an optimistic estimate. A conservative estimate of the MDC uses reasonably conservative values for parameters with a high level of uncertainty, and results in a MDC value that is higher than a non-conservative or optimistic estimate.

The instrument should be calibrated for the radiations and energies of interest at the site. This calibration should be traceable to an accepted standards organization such as the National Institute of Science and Technology (NIST). Routine operational checks of instrument performance should be conducted to assure that the check source response is maintained within acceptable ranges and that any changes in instrument background are not attributable to contamination of the detector. If the radionuclide contaminants cannot be detected at desired levels by direct measurement (Section 6.7), the portion of the survey dealing with measurements at discrete locations should be designed to rely primarily on sampling and laboratory analysis (Chapter 7).

Assuming the contaminants can be detected, either directly or by measuring a surrogate radionuclide in the mixture, the next decision point depends on whether the radionuclide being measured is present in background. Gross measurement methods will likely be more appropriate for measuring surface contamination in structures, scanning for locations of elevated activity, and determining exposure rates. Nuclide-specific measurement techniques, such as gamma spectrometry, provide a marked increase in detection sensitivity over gross measurements because of their ability to screen out contributions from other sources. Figure 4.2 illustrates the sequence of steps in determining if direct measurement techniques can be applied at a particular site, or if laboratory analysis is more appropriate. Scanning surveys are typically performed at all sites. The selection of appropriate instruments for scanning, direct measurement, and sampling and analysis should be survey specific.

4.7.2 Selection of Survey Techniques

In practice, the DQO process is used to obtain a proper balance among the use of various measurement techniques. In general, there is an inverse correlation between the cost of a specific measurement technique and the detection levels being sought. Depending on the survey objectives, important considerations include survey costs and choosing the optimum instrumentation and measurement mix.

A certain minimum number of direct measurements or samples will be needed to demonstrate compliance with the release criterion based on the nonparametric statistical tests (see Section 5.5.2). In addition, the potential for areas of elevated contamination will have to be considered for designing scanning surveys. Areas of elevated activity may also affect the number of measurements; however, scanning with survey instruments should generally be sufficient to

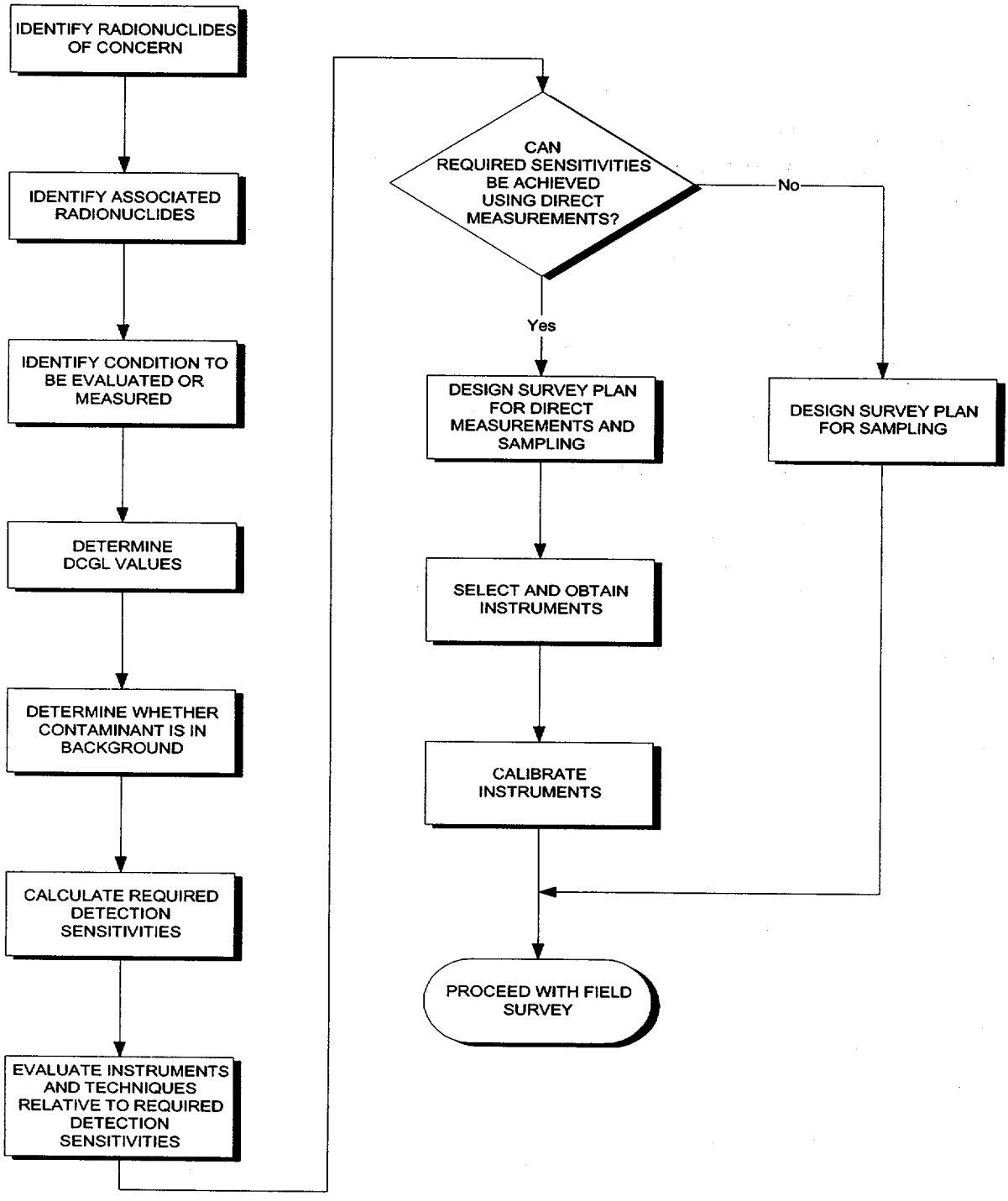


Figure 4.2 Flow Diagram for Selection of Field Survey Instrumentation for Direct Measurements and Analysis of Samples (Refer to Section 4.7)

ensure that no areas with unusually high levels of radioactivity are left in place. Some measurements may also provide information of a qualitative nature to supplement other measurements. An example of such an application is *in situ* gamma spectrometry to demonstrate the absence (or presence) of specific contaminants.

Table 4.1 presents a list of common contaminants along with recommended survey methods that have proven to be effective based on past survey experience in the decommissioning industry. This table provides a general indication of the detection capability of commercially-available instruments. As such, Table 4.1 may be used to provide an initial evaluation of instrument capabilities for some common radionuclides at the example DCGLs listed in the table. For example, consider the contamination of a surface with ^{241}Am. Table 4.1 indicates that ^{241}Am is detectable at the example DCGLs, and that viable direct measurement instruments include gas-flow proportional (α mode) and alpha scintillation detectors. Table 4.1 should not be interpreted as providing specific values for an instrument's detection sensitivity, which is discussed in Section 6.7. In addition, NRC draft report NUREG-1506 (NRC 1995) provides further information on factors that may affect survey instrumentation selection.

4.7.3 Criteria for Selection of Sample Collection and Direct Measurement Methods

Sample characteristics such as sample depth, volume, area, moisture level, and composition, as well as sample preparation techniques which may alter the sample, are important planning considerations for Data Quality Objectives. Sample preparation may include, but is not limited to, removing extraneous material, homogenizing, splitting, drying, compositing, and final preparation of samples. As is the case for determining survey unit characteristics, the physical sample characteristics and sampling method should be consistent with the dose or risk pathway modeling that is used to determine radionuclide DCGL's. If a direct measurement method is used, it should also be consistent with the pathway modeling.

For example, a sample depth of 15 cm (6 in.) for soil samples might be specified during the DQO process for a final status survey because this corresponds to the soil mixing or plow depth in several environmental pathway models (Yu *et al.*, 1993, NRC 1992b). If contamination exists at a depth less than this, a number of models uniformly mix it throughout this depth to simulate the soil mixing associated with plowing. Similarly, models may be based on dry weight, which may necessitate either drying samples or data transformation to account for dry weight.

The DQOs and subsequent direction to the laboratory for analysis might include removal of material not relevant for characterizing the sample, such as pieces of glass, twigs, or leaves. Table 4.2 provides examples of how a particular field soil composition of fine-, medium-, and coarse-grained materials might determine laboratory analysis DQOs for particular radionuclides. Fine materials consist of clay (less than 0.002 mm) and silt (0.002 to 0.062 mm). Medium materials consist of sand, which can be further divided into very fine, fine, medium, coarse, and very coarse sand. Coarse materials consist of gravel, which is composed of pebbles (2 to 64 mm), cobbles (64 to 256 mm), and boulders (greater than 256 mm) (Friedman 1978).

Table 4.1 Selection of Direct Measurement Techniques Based on Experience

Nuclide	Structure Surfaces		Land Areas		Direct Measurement Instruments[2]		
	Example DCGL[1] (Bq/m^2)	Detectable	Example DCGL[1] (Bq/kg)	Detectable	Surface Activity	Soil Activity	Exposure Rate
^{3}H	$1.6x10^{6}$	No	$1.5x10^{4}$	No	ND[6]	ND	ND
^{14}C	$4.7x10^{5}$	Yes	$1.4x10^{3}$	No	GPß	ND	ND
^{54}Mn	$1.3x10^{4}$	Yes	450	Yes	**GPß**[7],GM	γS,ISγ	**PIC**,γS,ISγ
^{55}Fe	$1.8x10^{6}$	No	$4.1x10^{5}$	No[5]	ND	ND(ISγ)	ND(ISγ)
^{60}Co	$3.1x10^{3}$	Yes	110	Yes	**GPß**,GM	γS,ISγ	**PIC**,γS,ISγ
^{63}Ni	$1.5x10^{6}$	Yes	$2.8x10^{5}$	No	GPß	ND	ND
^{90}Sr	$6.0x10^{3}$	Yes	420	No[5]	**GPß**,GM	ND (GM,GPß)	ND
^{99}Tc	$6.4x10^{5}$	Yes	$1.9x10^{3}$	No	**GPß**,GM	ND	ND
^{137}Cs	$8.2x10^{3}$	Yes	400	Yes	**GPß**,GM	γS,ISγ	**PIC**,γS,ISγ
^{152}Eu	$6.6x10^{3}$	Yes	240	Yes	**GPß**,GM	γS,ISγ	**PIC**,γS,ISγ
^{226}Ra (C)[3]	970	Yes	210	Yes	**GPα**,αS	γS,ISγ	**PIC**,γS,ISγ
^{232}Th (C)[3]	340	Yes	320	Yes	GPα,αS,**GPß**	γS,ISγ	**PIC**,γS,ISγ
U[4]	560	Yes	710	Yes	GPα,αS,**GPß**, ISγ	γS,**ISγ**, GPß	**PIC**,γS,ISγ
^{239}Pu, ^{240}Pu, ^{241}Pu	120	Yes	70	No[5]	**GPα**,αS	ND (ISγ)	ND
^{241}Am	110	Yes	70	Yes	**GPα**,αS	γS,ISγ	**PIC**,γS,ISγ

[1] Example DCGLs based on values given in NRC draft report NUREG-1500 (NRC 1994c).

[2] GPα = Gas-flow proportional counter (α mode)
GM = Geiger-Mueller survey meter
GPß = Gas-flow proportional counter (β mode)
PIC = Pressurized ionization chamber
αS = Alpha scintillation survey meter
γS = gamma scintillation (gross)
ISγ= *in situ* gamma spectrometry

[3] For decay chains having two or more radionuclides of significant half-life that reach secular equilibrium. The notation "(c)" indicates the direct measurement techniques assume the presence of progeny in the chain.

[4] Depleted, natural, and enriched.

[5] Possibly detectable at limits for areas of elevated activity.

[6] Not detectable.

[7] Bold indicates the preferred method where alternative methods are available.

Table 4.2 Example of DQO Planning Considerations

Separate out and evaluate fine-grain material because resuspension is associated with the fine grain fraction for the air pathway.
If contamination resides on sand, pebbles, and cobbles, analyze these materials for direct exposure pathway and analyze the fine-grain fraction for the air pathway.
Separation and homogenization are not necessary for analyses because direct exposure pathway depends upon the average concentration and presence of cobbles will usually not impact laboratory analysis.
Determine if pathway modeling considered the presence of cobbles.
Separate, homogenize, and evaluate fine-grain material because plant root uptake is associated with the fine-grain fraction for the plant ingestion pathway.
Separate, homogenize, and evaluate fine-grain materials because of their relevance for the contaminant source term for contaminant migration to the sub-surface for the water pathway.

Both sample depth and area are considerations in determining appropriate sample volume, and sample volume is a key consideration for determining the laboratory MDC. The depth should also correlate with the conceptual model developed in Chapter 3 and upgraded throughout the Radiation Survey and Site Investigation (RSSI) Process. For example, if data collected during the Historical Site Assessment indicate contamination may exist to a depth of greater than 15 cm (6 in.), then samples should be deep enough to support the survey objectives, such as for the scoping or characterization survey. Taking samples as a function of depth might also be a survey design objective, such as for scoping, characterization, or remediation support.

The depth and area of the sample should be recorded as well as any observations, such as the presence of materials noted during sampling. Chapter 6 and Chapter 7 present more detail regarding the application of these survey planning considerations.

4.8 Site Preparation

Site preparation involves obtaining consent for performing the survey, establishing the property boundaries, evaluating the physical characteristics of the site, accessing surfaces and land areas of interest, and establishing a reference coordinate system. Site preparation may also include removing equipment and materials that restrict access to surfaces. The presence of furnishings or equipment will restrict access to building surfaces and add additional items that the survey should address.

4.8.1 Consent for Survey

When facilities or sites are not owned by the organization performing the surveys, consent from the site or equipment owner should be obtained before conducting the surveys. All appropriate local, State, and Federal officials as well as the site owner and other affected parties should be notified of the survey schedule. Section 3.5 discusses consent for access, and additional guidance based on the CERCLA program is available from EPA (EPA 1987d).

4.8.2 Property Boundaries

Property boundaries may be determined from property survey maps furnished by the owners or from plat maps obtained from city or county tax maps. Large-area properties and properties with obscure boundaries or missing survey markers may require the services of a professional land surveyor.

If the radiological survey is only performed inside buildings, a tax map with the buildings accurately located will usually suffice for site/building location designation.

4.8.3 Physical Characteristics of Site

The physical characteristics of the site will have a significant impact on the complexity, schedule, and cost of a survey. These characteristics include the number and size of structures, type of building construction, wall and floor penetrations, pipes, building condition, total area, topography, soil type, and ground cover. In particular, the accessibility of structures and land areas (Section 4.8.4) has a significant impact on the survey effort. In some cases survey techniques (*e.g., in situ* gamma spectrometry discussed in Chapter 6) can preclude or reduce the need to gain physical access or use intrusive techniques. This should be considered during survey planning.

4.8.3.1 Structures

Building design and condition will have a marked influence on the survey efforts. The time involved in conducting a survey of building interior surfaces is essentially directly proportional to the total surface area. For this reason the degree of survey coverage decreases as the potential for residual activity decreases. Judgment measurements and sampling, which are performed in addition to the measurements performed for the nonparametric tests, are recommended in areas likely to have accumulated deposits of residual activity. As discussed in Section 5.5.3.3 and Section 8.5, judgment measurements and samples are compared directly to the appropriate DCGL.

The condition of surfaces after decontamination may affect the survey process. Removing contamination that has penetrated a surface usually involves removing the surface material. As a result, the floors and walls of decontaminated facilities are frequently badly scarred or broken up and are often very uneven. Such surfaces are more difficult to survey because it is not possible to maintain a fixed distance between the detector and the surface. In addition, scabbled or porous surfaces may significantly attenuate radiations—particularly alpha and low-energy beta particles. Use of monitoring equipment on wheels is precluded by rough surfaces, and such surfaces also pose an increased risk of damage to fragile detector probe faces. These factors should be considered during the calibration of survey instruments; NRC report NUREG-1507 (NRC 1997b) provides additional information on how to address these surface conditions. The condition of the building should also be considered from a safety and health standpoint before a survey is conducted. A structural assessment may be needed to determine whether the structure is safe to enter.

Expansion joints, stress cracks, and penetrations into floors and walls for piping, conduit, and anchor bolts, *etc.*, are potential sites for accumulation of contamination and pathways for migration into subfloor soil and hollow wall spaces. Drains, sewers, and septic systems can also become contaminated. Wall/floor interfaces are also likely locations for residual contamination. Coring, drilling, or other such methods may be necessary to gain access for survey. Intrusive surveying may require permitting by local regulatory authorities. Suspended ceilings may cover areas of potential contamination such as ventilation ducts and fixtures.

Exterior building surfaces will typically have a low potential for residual contamination, however, there are several locations that should be considered during survey planning. If there are roof exhausts, roof accesses that allow for radioactive material movement, or the facility is proximal to the air effluent discharge points, the possibility of roof contamination should be considered. Because roofs are periodically resurfaced, contaminants may be trapped in roofing material, and sampling this material may be necessary. Roof drainage points such as driplines along overhangs, downspouts, and gutters are also important survey locations. Wall penetrations for process equipment, piping, and exhaust ventilation are potential locations for exterior contamination.

Window ledges and outside exits (doors, doorways, landings, stairways, *etc.*) are also building exterior surfaces that should be addressed.

4.8.3.2 Land Areas

Depending upon site processes and operating history, the radiological survey may include varying portions of the land areas. Potentially contaminated open land or paved areas to be considered include storage areas (*e.g.*, equipment, product, waste, and raw material), liquid waste collection lagoons and sumps, areas downwind (based on predominant wind directions on an average annual basis, if possible) of stack release points, and surface drainage pathways. Additionally, roadways and railways that may have been used for transport of radioactive or contaminated materials that may not have been adequately contained could also be potentially contaminated.

Buried piping, underground tanks, sewers, spill areas, and septic leach fields that may have received contaminated liquids are locations of possible contamination may necessitate sampling of subsurface soil (Section 7.5.3). Information regarding soil type (*e.g.*, clay, sand) may provide insight into the retention or migration characteristics of specific radionuclides. The need for special sampling by coring or split-spoon equipment should be anticipated for characterization surveys.

If radioactive waste has been removed, surveys of excavated areas will be necessary before backfilling. If the waste is to be left in place, subsurface sampling around the burial site perimeter to assess the potential for future migration may be necessary.

Additionally, potentially contaminated rivers, harbors, shorelines, and other outdoor areas may require survey activities including environmental media (*e.g.*, sediment, marine biota) associated with these areas.

4.8.4 Clearing to Provide Access

In addition to the physical characteristics of the site, a major consideration is how to address inaccessible areas that have a potential for residual radioactivity. Inaccessible areas may need significant effort and resources to adequately survey. This section provides a description of common inaccessible areas that may have to be considered. The level of effort expended to access these difficult-to-reach areas should be commensurate with the potential for residual activity. For example, the potential for the presence of residual activity behind walls should be established before significant effort is expended to remove drywall.

4.8.4.1 Structures

Structures and indoor areas should be sufficiently cleared to permit completion of the survey. Clearing includes providing access to potentially contaminated interior surfaces (*e.g.*, drains, ducting, tanks, pits, ceiling areas, and equipment) by removing covers, disassembly, or other means of producing adequate openings.

Building features such as ceiling height, construction materials, ducts, pipes, *etc.*, will determine the ease of accessibility of various surfaces. Scaffolding, cranes, lifts, or ladders may be necessary to reach some surfaces, and dismantling portions of the building may be required.

The presence of furnishings and equipment will restrict access to building surfaces and add additional items that the survey should address. Remaining equipment indirectly involved in the process may need to be dismantled in order to evaluate the radiological status, particularly of inaccessible parts of the equipment. Removing or relocating certain furnishings, such as lab benches and hoods, to obtain access to potentially contaminated floors and walls may also be necessary. The amount of effort and resources dedicated to such removal or relocation activities should be commensurate with the potential for contamination. Where the potential is low, a few spot-checks may be sufficient to provide confidence that covered areas are free of contamination. In other cases, complete removal may be warranted.

Piping, drains, sewers, sumps, tanks, and other components of liquid handling systems present special difficulties because of the inaccessibility of interior surfaces. Process information, operating history, and preliminary monitoring at available access points will assist in evaluating the extent of sampling and measurements included in the survey.

If the building is constructed of porous materials (*e.g.*, wood, concrete) and the surfaces were not sealed, contamination may be found in the walls, floors, and other surfaces. It may be necessary to obtain cores of these surfaces for laboratory analysis.

Another accessibility problem is the presence of contamination beneath tile or other floor coverings. This often occurs because the covering was placed over contaminated surfaces, or the joints in tile were not sealed to prevent penetration. The practice in some facilities has been to "fix" contamination (particularly alpha emitters) by painting over the surface of the contaminated area. Thus, actions to obtain access to potentially contaminated surfaces, such as removing wall and floor coverings (including paint, wax, or other sealer) and opening drains and ducts, may be necessary to enable representative measurements of the contaminant. If alpha radiation or very low energy beta radiation is to be measured, the surface should be free of overlying material, such as dust and water, which may significantly attenuate the radiations.

4.8.4.2 Land Areas

If ground cover needs to be removed or if there are other obstacles that limit access by survey personnel or necessary equipment, the time and expense of making land areas accessible should be considered. In addition, precautionary procedures need to be developed to prevent spreading surface contamination during ground cover removal or the use of heavy equipment.

Removal or relocation of equipment and materials that may entail special precautions to prevent damage or maintain inventory accountability should be performed by the property owner whenever possible. Clearing open land of brush and weeds will usually be performed by a professional land-clearing organization under subcontract arrangements. However, survey personnel may perform minor land-clearing activities as needed.

An important consideration prior to clearing is the possibility of bio-uptake and consequent radiological contamination of the material to be cleared. Special precautions to avoid exposure of personnel involved in clearing activities may be necessary. Initial radiological screening surveys should be performed to ensure that cleared material or equipment is not contaminated.

The extent of site clearing in specific areas depends primarily on the potential for radioactive contamination existing in those areas where: 1) the radiological history or results of previous surveys do not indicate potential contamination of an area (it may be sufficient to perform only minimum clearing to establish a reference coordinate system); 2) contamination is known to exist or a high potential for contamination necessitates completely clearing an area to provide access to all surfaces; and 3) new findings as the survey progresses may indicate that additional clearing be performed.

Open land areas may be cleared by heavy machinery (*e.g.*, bulldozers, bushhogs, and hydroaxes). However, care should be exercised to prevent relocation of surface contamination or damage to site features such as drainage ditches, utilities, fences, and buildings. Minor land clearing may be performed using manually operated equipment such as brushhooks, power saws, knives, and string trimmers. Brush and weeds should be cut to the minimum practical height necessary to facilitate measurement and sampling activities (approximately 15 cm). Care should be exercised to prevent unnecessary damage to or removal of mature trees or shrubs.

Potential ecological damage that might result from an extensive survey should be considered. If a survey is likely to result in significant or permanent damage to the environment, appropriate environmental analyses should be conducted prior to initiating the survey. In addition, environmental hazards such as poison ivy, ticks carrying Lyme disease, and poisonous snakes, spiders, or insects should be noted. These hazards can affect the safety and health of the workers as well as the schedule for performing the survey.

4.8.5 Reference Coordinate System

Reference coordinate systems are established at the site to:

- facilitate selection of measurement and sampling locations
- provide a mechanism for referencing a measurement to a specific location so that the same survey point can be relocated

A survey reference coordinate system consists of a grid of intersecting lines, referenced to a fixed site location or benchmark. Typically, the lines are arranged in a perpendicular pattern, dividing the survey location into squares or blocks of equal area; however, other types of patterns (*e.g.*, three-dimensional, polar) have been used.

The reference coordinate system used for a particular survey should provide a level of reproducibility consistent with the objectives of the survey. For example, a commercially available global positioning system will locate a position within tens of meters, while a differential global positioning system (DGPS) provides precision on the order of a few centimeters (see Section 6.10.1.1). On the other hand, a metal bar can be driven into the ground to provide a long-term reference point for establishing a local reference coordinate system.

Reference coordinate system patterns on horizontal surfaces are usually identified numerically on one axis and alphabetically on the other axis or in distances in different compass directions from the grid origin. Examples of structure interior and land area grids are shown in Figures 4.3 through 4.5. Grids on vertical surfaces may include a third designator, indicating position relative to floor or ground level. Overhead measurement and sampling locations (*e.g.*, ceiling and overhead beams) are referenced to corresponding floor grids.

For surveys of Class 1 and Class 2 areas, basic grid patterns at 1 to 2 meter intervals on structure surfaces and at 10 to 20 meter intervals of land areas may be sufficient to identify survey locations with a reasonable level of effort, while not being prohibitive in cost or difficulty of installation. Gridding of Class 3 areas may also be necessary to facilitate referencing of survey locations to a common system or origin but, for practical purposes, may typically be at larger intervals—*e.g.*, 5 to 10 meters for large structural surfaces and 20 to 50 meters for land areas.

Reference coordinate systems on structure surfaces are usually marked by chalk line or paint along the entire grid line or at line intersections. Land area reference coordinate systems are usually marked by wooden or metal stakes, driven into the surface at reference line intersections. The selection of an appropriate marker depends on the characteristics and routine uses of the surface. Where surfaces prevent installation of stakes, the reference line intersection can be marked by painting.

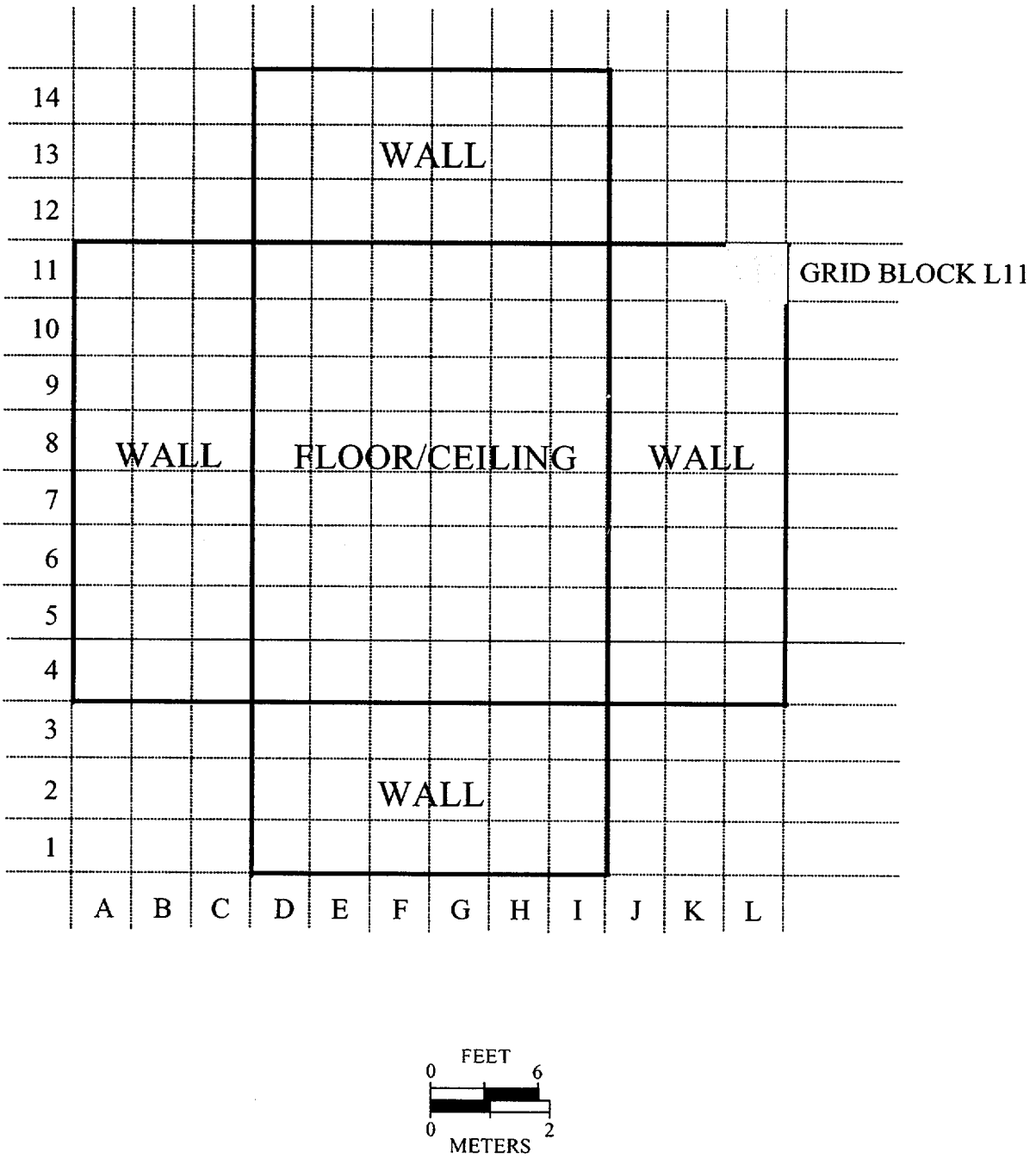
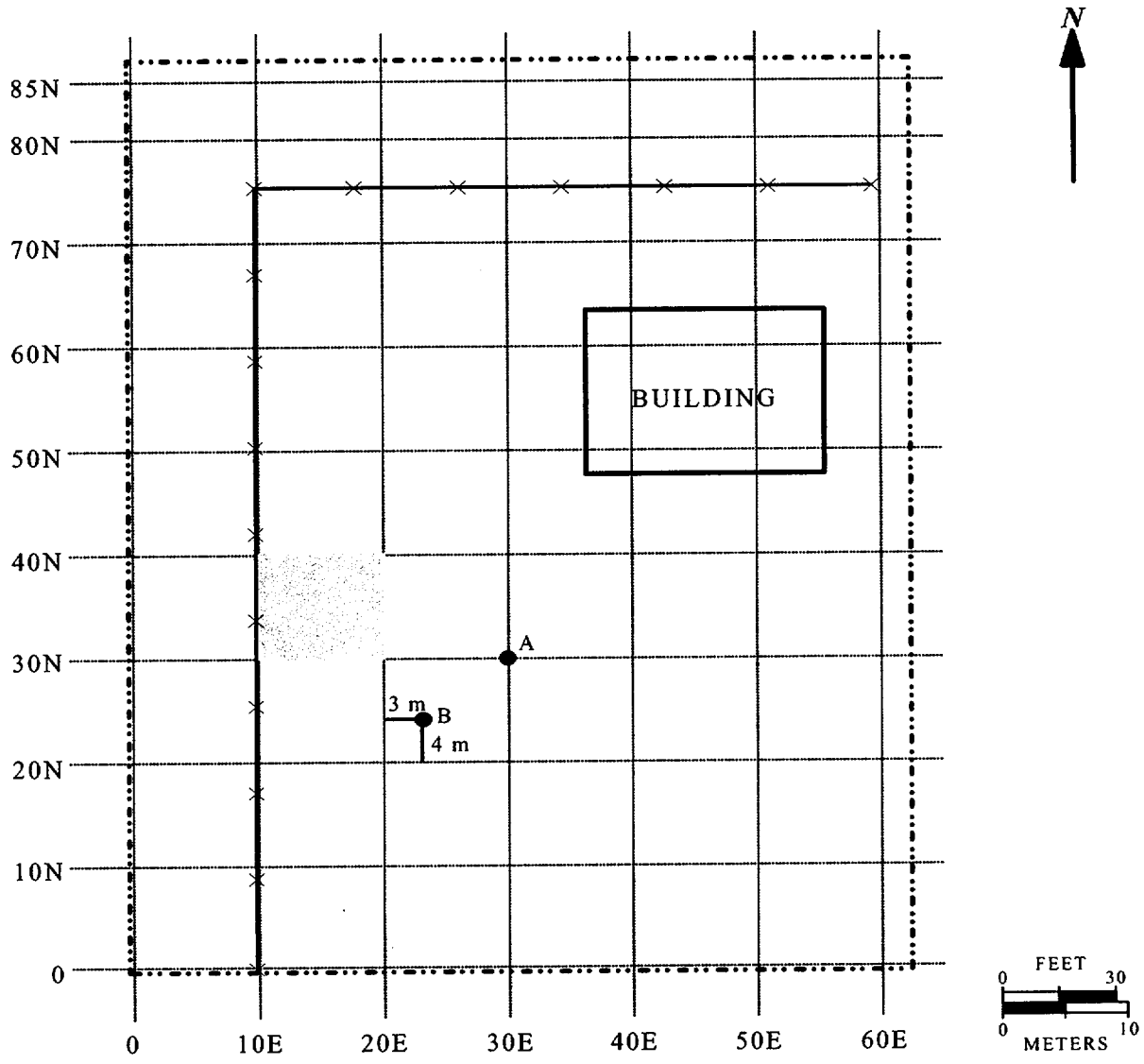


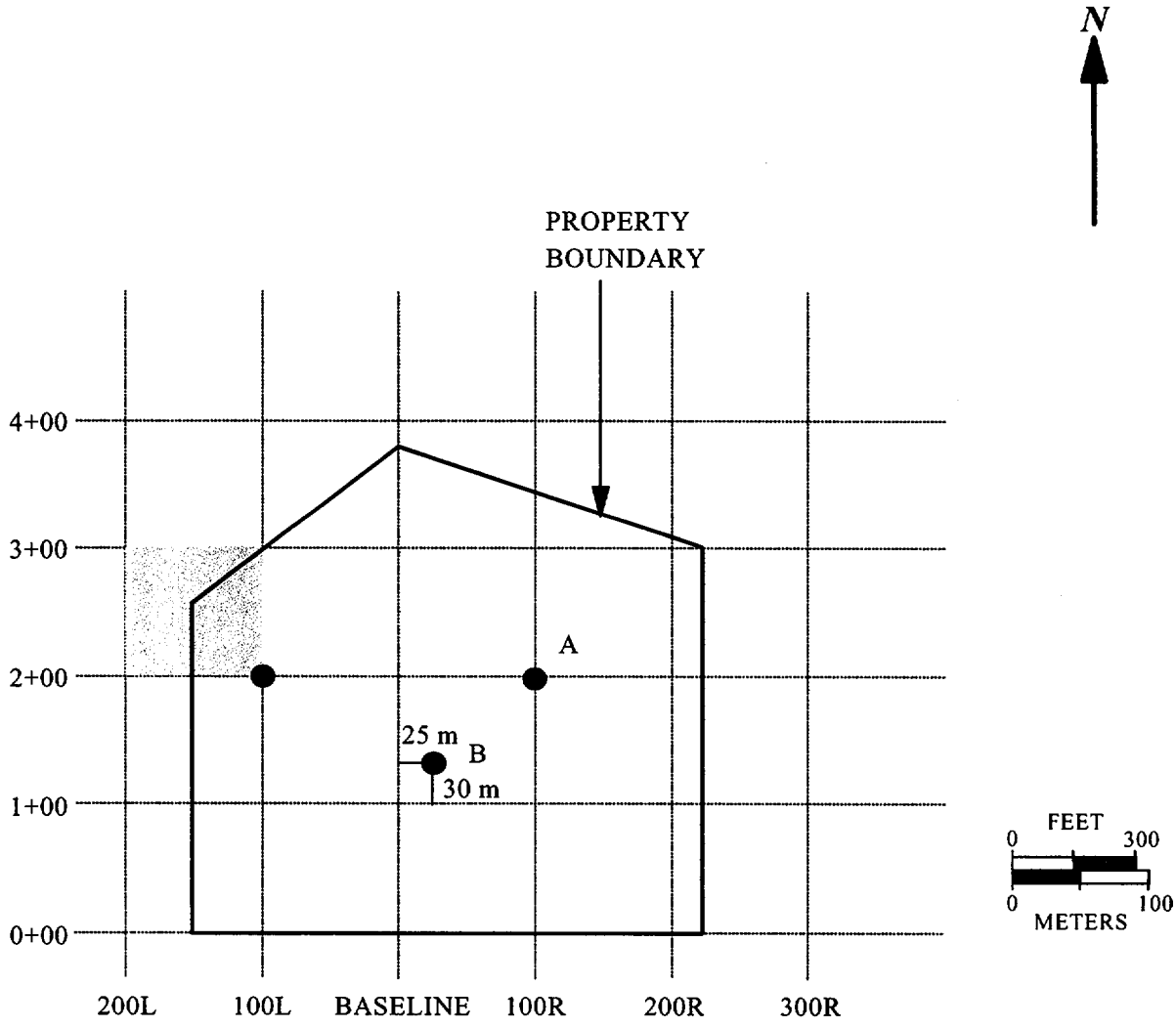
Figure 4.3 Indoor Grid Layout with Alphanumeric Grid Block Designation: Walls and Floors are Diagramed as Though They Lay Along the Same Horizontal Plane



POINT A GRID COORDINATES 30E, 30N
POINT B GRID COORDINATES 23E, 24N
SHADED BLOCK GRID COORDINATES 10E, 30N

SURVEY UNIT BOUNDARY
ONSITE FENCE

Figure 4.4 Example of a Grid System for Survey of Site Grounds Using Compass Directions



POINT A GRID COORDINATES 100R, 2+00
POINT B GRID COORDINATES 25R, 1+30
SHADED BLOCK GRID COORDINATES 200L, 2+00

Figure 4.5 Example of a Grid System for Survey of Site Grounds Using Distances Left or Right of the Baseline

Three basic coordinate systems are used for identifying points on a reference coordinate system. The reference system shown in Figure 4.3 references grid locations using numbers on the vertical axis and letters on the horizontal axis. The reference system shown on Figure 4.4 references distances from the 0,0 point using the compass directions N (north), S (south), E (east), and W (west). The reference system shown in Figure 4.5 references distances along and to the R (right) or L (left) of the baseline. In addition, a less frequently used reference system is the polar coordinate system, which measures distances along transects from a central point. Polar coordinate systems are particularly useful for survey designs to evaluate effects of stack emissions, where it may be desirable to have a higher density of samples collected near the stack and fewer samples with increasing distance from the stack.

Figure 4.5 shows an example grid system for an outdoor land area. The first digit or set of digits includes an L or R (separated from the first set by a comma) to indicate the distance from the baseline in units (meters) and the direction (left or right) from the baseline. The second digit or set of digits refers to the perpendicular distance from the 0,0 point on the baseline and is measured in hundreds of units. Point A in the example of a reference coordinate system for survey of site grounds, Figure 4.5, is identified 100R, 2+00 (*i.e.*, 200 m from the baseline and 100 m to the right of the baseline). Fractional distances between reference points are identified by adding the distance beyond the reference point and are expressed in the same units used for the reference coordinate system dimensions. Point B on Figure 4.5 is identified 25R, 1+30.

Open land reference coordinate systems should be referenced to a location on an existing State or local reference system or to a U.S. Geological Survey (USGS) bench mark. (This may require the services of a professional land surveyor.) Global positioning systems (GPS) are capable of locating reference points in terms of latitude and longitude (Section 6.10.1 provides descriptions of positioning systems).

Following establishment of the reference coordinate system, a drawing is prepared by the survey team or the land surveyor. This drawing indicates the reference lines, site boundaries, and other pertinent site features and provides a legend showing the scale and a reference compass direction. The process used to develop the reference coordinate system should be recorded in the survey planning documentation (*e.g.*, the Quality Assurance Project Plan or QAPP). An deviations from the requirements developed during planning should be documented when the reference coordinate system is established.

It should be noted that the reference coordinate systems described in this section are intended primarily for reference purposes and do not necessarily dictate the spacing or location of survey measurements or samples. Establishment of a measurement grid to demonstrate compliance with the DCGL is discussed in Section 5.5.2.5 and Chapter 8.

4.9 Quality Control

Site surveys should be performed in a manner that ensures results are accurate and sources of uncertainty are identified and controlled. This is especially the case for final status surveys that are vital to demonstrating a facility satisfies pre-established release criteria. Quality control (QC) and quality assurance (QA) are initiated at the start of a project and integrated into all surveys as DQOs are developed. This carries over to the writing of a Quality Assurance Project Plan (QAPP), which applies to each aspect of a survey. Section 9.2 provides guidance on developing a QAPP. Data quality is routinely a concern throughout the RSSI Process, and one should recognize that QA/QC procedures will change as data are collected and analyzed, and as DQOs become more rigorous for the different types of surveys that lead up to a final status survey.

In general, surveys performed by trained individuals are conducted with approved written procedures and properly calibrated instruments that are sensitive to the suspected contaminant. However, even the best approaches for properly performing measurements and acquiring accurate data need to consider QC activities. QC activities are necessary to obtain additional quantitative information to demonstrate that measurement results have the required precision and are sufficiently free of errors to accurately represent the site being investigated. The following two questions are the main focus of the rationale for the assessment of errors in environmental data collection activities (EPA 1990).

- How many and what type of measurements are required to assess the quality of data from an environmental survey?

- How can the information from the quality assessment measurements be used to identify and control sources of error and uncertainties in the measurement process?

These questions are introduced as part of guidance that also includes an example to illustrate the planning process for determining a reasonable number of quality control (QC) measurements. This guidance also demonstrates how the information from the process may be used to document the quality of the measurement data. This process was developed in terms of soil samples collected in the field and then sent to a laboratory for analysis (EPA 1990). For MARSSIM, these questions may be asked in relation to measurements of surface soils and building surfaces both of which include sampling, scanning, and direct measurements.

Quality control may be thought of in three parts: 1) determining the type of QC samples needed to detect precision or bias; 2) determining the number of samples as part of the survey design; and 3) scheduling sample collections throughout the survey process to identify and control sources of error and uncertainties. Section 4.9.1 introduces the concepts of precision and bias related to survey measurements and briefly discusses the types of QC measurements needed to detect and quantify precision and bias. Section 6.2 and Section 7.2 provide more detailed guidance on the

types of QC measurements. The number of QC measurements is addressed in Section 4.9.2, while Section 4.9.3 and Section 9.3 contain information on identifying and controlling sources of uncertainty. Overall, survey activities associated with MARSSIM include obtaining the additional information related to QA of both field and laboratory activities.

4.9.1 Precision and Systematic Errors (Bias)

Precision is a measure of agreement among repeated measurements. Precision is discussed further in Appendix N in statistical terms. Table N.2 presents the minimum considerations, impacts of not meeting these considerations, and corrective actions associated with assessing precision. Systematic errors, also called bias, accumulate during the measurement process and result from faults in sampling designs and procedures, analytical procedures, sample contamination, losses, interactions with containers, deterioration, inaccurate instrument calibration, and other sources. Bias causes the mean value of the sample data to be consistently higher or lower than the true mean value. Appendix N also discusses bias, and Table N.3 presents the minimum considerations associated with assessing bias, the impacts if the considerations are not met, and related corrective actions. Laboratories typically introduce QC samples into their sample load to assess possible bias. In simplest terms, spikes, repeated measurements, and blanks are used to assess bias, precision, and contamination, respectively. See Section 6.2 for further discussion of specific measurements for determining precision and bias for scans and direct measurements and Section 7.2 for further discussion of specific measurements for determining precision and bias for samples.

Field work using scanning or direct measurements eliminates some sources of error because samples are not removed, containerized, nor transported to another location for analysis. The operator's technique or field instrument becomes the source of bias. In this case, detecting bias might incorporate field replicates (see Section 7.2.2.1) by having a second operator to revisit measurement locations and following the same procedure with the same instrument as was used by the first operator. This is an approach used to assess precision of measurements. A field instrument's calibration can also be checked by one or more operators during the course of a survey and recorded on a control chart. Differences in set up or handling of instruments by different operators may reveal a significant source of bias that is quite different from sources of bias associated with laboratory work.

The following factors should be considered when evaluating sources of bias, error, and uncertainty. Contamination is an added factor to consider for each of the following items.

- sample collection methods
- handling and preparation of samples
- homogenization and aliquots of laboratory samples
- field methods for sampling, scanning, or direct measurements

- laboratory analytical process
- total bias contributed by all sources

The magnitude of the measurement system variability should be evaluated to determine if the variability approaches or exceeds the true but unknown variability in the population of interest. Errors, bias, or data variability may accumulate to the point of rendering data unusable to achieve survey objectives. Systematic investigations of field or laboratory processes can be initiated to assess and identify the extent of errors, bias, and data variability and to determine if the DQOs are achieved. An important aspect of each QC determination is the representative nature of a sample or measurement (see Appendix N for a description of representativeness). If additional samples or measurements are not taken according to the appropriate method, the resulting QC information will be invalid or unusable. For example, if an inadequate amount of sample is collected, the laboratory analytical procedure may not yield a proper result. The QC sample must represent the sample population being studied. Misrepresentation itself creates a bias that if undetected leads to inaccurate conclusions concerning an analysis. At the very least, misrepresentation leads to a need for additional QA investigation.

4.9.2 Number of Quality Control Measurements

The number of QC measurements is determined by the available resources and the degree to which one needs assurance that a measurement process is adequately controlled. The process is simplified, for example, when the scope of a survey is narrowed to a single method, one sampling crew, and a single laboratory to analyze field samples. Increasing the number of samples and scheduling sample collections and analyses over time or at different laboratories increases the level of difficulty and necessitates increasing the number of QC measurements. The number of QC measurements may also be driven upward as the action level approaches a given instrument's detection limit. This number is determined on a case-by-case basis, where the specific contaminant and instruments are assessed for detecting a particular radionuclide.

A widely used standard practice is to collect a set percentage, such as 5% (EPA 1987b), of samples for QA purposes. However, this practice has disadvantages. For example, it provides no real assessment of the uncertainties for a relatively small sample size. For surveys where the required number of measurements increases, there may be a point beyond which there is little added value in performing additional QC measurements. Aside from cost, determining the appropriate number of QC measurements essentially depends on site-specific factors. For example, soil may present a complex and variable matrix requiring many more QC measurements for surface soils than for building surfaces.

A performance based alternative (EPA 1990) to a set percentage or rule of thumb can be implemented. First, potential sources of error or uncertainty, the likelihood of occurrence, and the consequences in the context of the DQOs should be determined. Then, the appropriate type

and number of QC measurements based on the potential error or uncertainty are determined. For example, field replicate samples (*i.e.*, a single sample that is collected, homogenized, and split into equivalent fractions in the field) are used to estimate the combined contribution of several sources of variation. Hence, the number of field replicate samples to be obtained in the study should be dictated by how precise the estimate of the total measurement should be.

Factors influencing this estimate include the

- number of measurements
- number and experience of personnel involved
- current and historical performance of sampling and analytical procedures used
- the variability of survey unit and background reference area radioactivity measurement systems used
- number of laboratories used
- the level of radioactivity in the survey unit (which for a final status survey should be low)
- how close an action level (*e.g.*, DCGL) is to a detection limit (which may represent a greater concern after reducing or removing radionuclide concentrations by remediation)

The precision of an estimate of the "true" variance for precision or bias within a survey design depends on the number of degrees of freedom used to provide the estimate. Table 4.3 provides the one-sided upper confidence limits for selected degrees of freedom assuming the results of the measurements are normally distributed. Confidence limits are provided for 90, 95, 97.5, and 99 percent confidence levels. At the stated level of confidence, the "true" variance of the estimate of precision or bias for a specified number of QC measurements will be between zero and the multiple of the estimated variance listed in Table 4.3. For example, for five degrees of freedom one would be 90% confident that the true variance for precision falls between zero and 3.10 times the estimated variance. The number of QC measurements is equal to one greater than the degrees of freedom.

When planning surveys, the number of each type of QC measurement can be obtained from Table 4.3. For example, if the survey objective is to estimate the variance in the bias for a specific measurement system between zero and two times the estimated variance at a 95% confidence level, 15 degrees of freedom or 16 measurements of a material with known concentration (*e.g.*, performance evaluation samples) would be indicated. MARSSIM recommends that the survey objective be set such that the true variance falls between zero and two times the estimated variance. The level of confidence is then determined on a site-specific basis to adjust the number of each type of QC measurement to the appropriate level (*i.e.*, 11, 16, 21 or 31 measurements). The results of the QC measurements are evaluated during the assessment phase of the data life cycle (see Section 9.3 and Appendix N).

Table 4.3 Upper Confidence Limits for the True Variance as a Function of the Number of QC Measurements Used to Determine the Estimated Variance (EPA 1990)

Degrees of Freedom*	Level of Confidence (%)			
	90	95	97.5	99
2	9.49	19.49	39.21	99.50
5	3.10	4.34	6.02	9.02
10	2.05	2.54	3.08	3.91
15	1.76	2.07	2.40	2.87
20	1.61	1.84	2.08	2.42
25	1.52	1.71	1.91	2.17
30	1.46	1.62	1.78	2.01
40	1.38	1.51	1.64	1.80
50	1.33	1.44	1.61	1.68
100	1.21	1.28	1.35	1.43

* To obtain the necessary number of quality control measurements, add one to the degrees of freedom.

Example:

A site is contaminated with ^{60}Co and consists of four Class 1 interior survey units, nine Class 2 interior survey units, two Class 3 interior survey units, and one Class 3 exterior survey unit. Three different measurement systems are specified in the survey design for performing scanning surveys, one measurement system is specified for performing direct measurements for interior survey units, and one measurement system is specified for measuring samples collected from the exterior survey unit.

Repeated measurements are used to estimate precision. For scan surveys there is not a specified number of measurements. 10% of the scans in each Class 1 survey unit were repeated as replicates to measure operator precision (see Section 6.2.2.1) within 24 hours of the original scan survey. 5% of each Class 2 and Class 3 survey unit were similarly repeated as replicates to measure operator precision. The results of the repeated scans were evaluated based on professional judgment. For direct measurements and sample collection activities, a 95% confidence level was selected as consistent with the objectives of the survey. Using Table 4.3, it was determined that 16 repeated measurements were required for both the direct measurement technique and the sample collection and laboratory measurement technique. Because 72 direct measurements would be performed in Class 1 survey units, 99 in Class 2 survey units, and 20 in Class 3 survey units, it was anticipated that at least 16 direct measurements would have sufficient activity above

background to perform repeated measurements and obtain usable results (see Section 5.5.2 for guidance on determining the number of measurements and Appendix A for a more detailed discussion of the example site). The 16 direct measurement locations to be repeated would be selected based on the results of the direct measurements and would represent the entire usable range of activity found in the survey units rather than measuring the 16 locations with the highest activities. (The usable range of activity includes the highest measurement result in the survey unit and the lowest measurement result with an acceptable measurement uncertainty compared to the desired level of precision.) The repeated measurements would be performed by different operators using the same equipment, but they would not know the results of the original survey. To ensure that the measurements would be valid, the QC measurements to check for contamination would be performed at the same time. Because the laboratory's QA program called for periodic checks on the precision of the laboratory instruments, the total survey design precision for laboratory measurements was measured. Because the only samples collected would come from a Class 3 area, the sample activities were expected to be close to or below the measurement system MDC. This meant that field replicate samples would not provide any usable information. Also, QC samples for bias were repeated to obtain a usable estimate of precision for the survey design.

Measurements of materials with known concentrations above background (*e.g.*, performance evaluation samples) and known concentrations at or below background (*e.g.*, field blanks) are used to estimate bias. For scan surveys, the repeated scanning performed to estimate precision would also serves as a check for contamination using blanks. Because there was no appropriate material of known concentration on which to perform bias measurements, the calibration checks were used to demonstrate that the instruments were reading properly during the surveys. A control chart was developed using the instrument response for an uncalibrated check source. Measurements were obtained using a specified source-detector alignment that could be easily repeated. Measurements were obtained at several times during the day over a period of several weeks prior to taking the instruments into the field. Calibration checks were performed before and after each survey period in the field and the results immediately plotted on the control chart to determine if the instrument was performing properly. This method was also adopted for the direct measurement system. 20 samples were required by the survey design for the Class 3 exterior survey unit. To ensure that the samples were truly blind for the laboratory, samples three times the requested volume were collected. These samples were sent to a second laboratory for preparation. Each sample was weighed, dried, and reweighed to determine the moisture content. Then each sample was ground to a uniform particle size of 1 mm (approximately 16 mesh) and divided into three separate aliquots (each aliquot was the same size). For each sample one aliquot was packaged for transport to the laboratory performing the analysis. After these samples were packaged, 16 of the samples had both of the remaining aliquots spiked with the same level of activity using a source

solution traceable to the National Institute of Science and Technology (NIST). The 16 samples each had a different level of activity within a range that was accepted by the laboratory performing the analysis. These 32 samples were also packaged for transport to the laboratory. In addition, 16 samples of a soil similar to the soil at the site were prepared as blanks to check against contamination. The 20 samples, 32 spikes, and 16 blanks were transported to the laboratory performing the analyses in a single shipment so that all samples were indistinguishable from each other except by the sample identification.

4.9.3 Controlling Sources of Error

During the performance of a survey, it is important to identify sources of error and uncertainty early in the process so that problems can be resolved. The timing of the QC measurements within the survey design can be very important. In order to identify problems as early as possible, it may be necessary to perform a significant number of QC measurements early in the survey. This can be especially important for surveys utilizing an innovative or untested survey design. Survey designs that have been used previously and produced reliable results may be able to space the QC measurement evenly throughout the survey, or even wait to have samples analyzed at the end of the survey, as long as the objectives of the survey are achieved.

For example, a survey design requires a new scanning method to be used for several survey units when there are little performance data available for this technique. To ensure that the technique is working properly, the first few survey units are re-scanned to provide an initial estimate of the precision and bias. After the initial performance of the techniques has been verified, a small percentage of the remaining survey units is re-scanned to demonstrate that the technique is operating properly for the duration of the survey.

Identifying sources of error and uncertainty is only the first step. Once the sources of uncertainty have been identified, they should be minimized and controlled for the rest of the survey. Section 9.3 discusses the assessment of survey data and provides guidance on corrective actions that may be appropriate for controlling sources of error or uncertainty after they have been identified.

4.10 Health and Safety

Consistent with the approach for any operation, activities associated with the radiological surveys should be planned and monitored to assure the health and safety of the worker and other personnel, both onsite and offsite, are adequately protected. At the stage of determining the final status of the site, residual radioactivity is expected to be below the DCGL values; therefore, the final status survey should not include radiation protection controls. However, radiation protection controls may be necessary when performing scoping or characterization surveys where the potential for significant levels of residual radioactivity is unknown.

Significant health and safety concerns during any radiological survey include the potential industrial hazards commonly found at a construction site, such as exposed electrical circuitry, excavations, enclosed work spaces, hazardous atmospheres, insects, poisonous snakes, plants, and animals, unstable surfaces (*e.g.*, wet or swamp soil), heat and cold, sharp objects or surfaces, falling objects, tripping hazards, and working at heights. The survey plan should incorporate objectives and procedures for identifying and eliminating, avoiding, or minimizing these potential safety hazards.

5 SURVEY PLANNING AND DESIGN

5.1 Introduction

This chapter is intended to assist the user in planning a strategy for conducting a final status survey, with the ultimate objective being to demonstrate compliance with the derived concentration guideline levels (DCGLs). The survey types that make up the Radiation Survey and Site Investigation (RSSI) Process include scoping, characterization, remedial action support, and final status surveys. Although the scoping, characterization, and remedial action support surveys have multiple objectives, this manual focuses on those aspects related to supporting the final status survey and demonstrating compliance with DCGLs. In general, each of these survey types expands upon the data collected during the previous survey (*e.g.*, the characterization survey is planned with information collected during the scoping survey) up through the final status survey. The purpose of the final status survey is to demonstrate that the release criterion established by the regulatory agency has not been exceeded. This final release objective should be kept in mind throughout the design and planning phases for each of the other survey types. For example, scoping surveys may be designed to meet the objectives of the final status survey such that the scoping survey report is also the final status survey report. The survey and analytical procedures referenced in this chapter are described in Chapter 6, Chapter 7, and Appendix H. An example of a final status survey, as described in Section 5.5, appears in Appendix A. In addition, example checklists are provided for each type of survey to assist the user in obtaining the necessary information for planning a final status survey.

5.2 Scoping Surveys

5.2.1 General

If the data collected during the Historical Site Assessment (HSA) indicate that a site or area is impacted, a scoping survey could be performed. The objective of this survey is to augment the HSA for sites with potential residual contamination. Specific objectives may include: 1) performing a preliminary risk assessment and providing data to complete the site prioritization scoring process (CERCLA and RCRA sites only), 2) providing input to the characterization survey design, if necessary, 3) supporting the classification of all or part of the site as a Class 3 area for planning the final status survey, 4) obtaining an estimate of the variability in the residual radioactivity concentration for the site, and 5) identifying non-impacted areas that may be appropriate for reference areas and estimating the variability in radionuclide concentrations when the radionuclide of interest is present in background.

Scoping survey information needed when conducting a preliminary risk assessment (as noted above for CERCLA and RCRA sites) includes the general radiation levels at the site and gross levels of residual contamination on building surfaces and in environmental media. If unexpected

conditions are identified that prevent the completion of the survey, the MARSSIM user should contact the responsible regulatory agency for further guidance. Sites that meet the National Contingency Plan criteria for a removal should be referred to the Superfund Removal program (EPA 1988c).

If the HSA indicates that contamination is likely, a scoping survey could be performed to provide initial estimates of the level of effort for remediation and information for planning a more detailed survey, such as a characterization survey. Not all radiological parameters need to be assessed when planning for additional characterization because total surface activity or limited sample collection may be sufficient to meet the objectives of the scoping survey.

Once a review of pertinent site history indicates that an area is impacted, the minimum survey coverage at the site will include a Class 3 area final status survey prior to the site being released. For scoping surveys with this objective, identifying radiological decision levels is necessary for selecting instruments and procedures with the necessary detection sensitivities to demonstrate compliance with the release criterion. A methodology for planning, conducting, and documenting scoping surveys is described in the following sections.

5.2.2 Survey Design

Planning a scoping survey involves reviewing the HSA (Chapter 3). This process considers available information concerning locations of spills or other releases of radioactive material. Reviewing the radioactive materials license or similar documentation provides information on the identity, locations, and general quantities of radioactive material used at the site. This information helps to determine which areas are likely to contain residual radioactivity and, thus, areas where scoping survey activities will be concentrated. The information may also identify one or more non-impacted areas as potential reference areas when radionuclides of concern are present in background (Section 4.5). Following the review of the HSA, DCGLs that are appropriate for the site are selected. The DCGLs may be adjusted later if a determination is made to use site-specific information to support the development of DCGLs.

If residual radioactivity is identified during the scoping survey, the area may be classified as Class 1 or Class 2 for final status survey planning (refer to Section 4.4 for guidance on initial classification), and a characterization survey is subsequently performed. For scoping surveys that are designed to provide input for characterization surveys, measurements and sampling may not be as comprehensive or performed to the same level of sensitivity necessary for final status surveys. The design of the scoping survey should be based on specific data quality objectives (DQOs; see Section 2.3.1 and Appendix D) for the information to be collected.

For scoping surveys that potentially serve to release the site from further consideration, the survey design should consist of sampling based on the HSA data and professional judgment. If residual

radioactivity is *not* identified during judgment sampling, it may be appropriate to classify the area as Class 3 and perform a final status survey for Class 3 areas. Refer to Section 5.5 for a description of final status surveys. However, collecting additional information during subsequent surveys (*e.g.*, characterization surveys) may be necessary to make a final determination as to area classification.

5.2.3 Conducting Surveys

Scoping survey activities performed for preliminary risk assessment or to provide input for additional characterization include a limited amount of surface scanning, surface activity measurements, and sample collection (smears, soil, water, vegetation, paint, building materials, subsurface materials). In this case, scans, direct measurements, and samples are used to examine areas likely to contain residual radioactivity. These activities are conducted based on HSA data, preliminary investigation surveys, and professional judgment.

Background activity and radiation levels for the area should be determined, including direct radiation levels on building surfaces and radionuclide concentrations in media. Survey locations should be referenced to grid coordinates, if appropriate, or fixed site features. It may be considered appropriate to establish a reference coordinate system in the event that contamination is detected above the DCGLs (Section 4.8.5). Samples collected as part of a scoping survey should consider any sample tracking requirements, including chain of custody, if required (Section 7.8).

Scoping surveys that are expected to be used as Class 3 area final status surveys should be designed following the guidance in Section 5.5. These surveys should also include judgment measurements and sampling in areas likely to have accumulated residual radioactivity (Section 5.5.3).

5.2.4 Evaluating Survey Results

Survey data are converted to the same units as those in which DCGLs are expressed (Section 6.6). Identification of potential radionuclide contaminants at the site is performed using direct measurements or laboratory analysis of samples. The data are compared to the appropriate regulatory DCGLs.

For scoping survey activities that provide an initial assessment of the radiological hazards at the site, or provide input for additional characterization, the survey data are used to identify locations and general extent of residual radioactivity. Scoping surveys that are expected to be used as Class 3 area final status surveys should follow the methodology presented in Chapter 8 to determine if the release criterion has been exceeded.

5.2.5 Documentation

How the results of the scoping survey are documented depends on the specific objectives of the survey. For scoping surveys that provide additional information for characterization surveys, the documentation should provide general information on the radiological status of the site. Survey results should include identification of the potential contaminants (including the methods used for radionuclide identification), general extent of contamination (*e.g.*, activity levels, area of contamination, and depth of contamination), and possibly even relative ratios of radionuclides to facilitate DCGL application. A narrative report or a report in the form of a letter may suffice for scoping surveys used to provide input for characterization surveys. Sites being released from further consideration should provide a level of documentation consistent with final status survey reports.

EXAMPLE SCOPING SURVEY CHECKLIST

SURVEY DESIGN

_____ Enumerate DQOs: State the objectives of the survey; survey instrumentation capabilities should be appropriate for the specified survey objectives.

_____ Review the Historical Site Assessment for:

- _____ Operational history (*e.g.*, problems, spills, releases, or notices of violation) and available documentation (*e.g.*, radioactive materials license).
- _____ Other available resources—site personnel, former workers, residents, *etc.*
- _____ Types and quantities of materials that were handled and where radioactive materials were stored, handled, moved, relocated, and disposed.
- _____ Release and migration pathways.
- _____ Areas that are potentially affected and likely to contain residual contamination. Note: Survey activities will be concentrated in these areas.
- _____ Types and quantities of materials likely to remain onsite—consider radioactive decay.

_____ Select separate DCGLs for the site based on the HSA review. (It may be necessary to assume appropriate regulatory DCGLs in order to permit selection of survey methods and instrumentation for the expected contaminants and quantities.)

CONDUCTING SURVEYS

_____ Follow the survey design documented in the QAPP. Record deviations from the stated objectives or documented SOPs and document additional observations made when conducting the survey.

_____ Select instrumentation based on the specific DQOs of the survey. Consider detection capabilities for the expected contaminants and quantities.

_____ Determine background activity and radiation levels for the area; include direct radiation levels on building surfaces, radionuclide concentrations in media, and exposure rates.

_____ Record measurement and sample locations referenced to grid coordinates or fixed site features.

_____ For scoping surveys that are conducted as Class 3 area final status surveys, follow guidance for final status surveys.

_____ Conduct scoping survey, which involves judgment measurements and sampling based on HSA results:

- _____ Perform investigatory surface scanning.
- _____ Conduct limited surface activity measurements.
- _____ Perform limited sample collection (smears, soil, water, vegetation, paint, building materials, subsurface materials).
- _____ Maintain sample tracking.

EVALUATING SURVEY RESULTS

_____ Compare survey results with the DQOs.

_____ Identify radionuclides of concern.

_____ Identify impacted areas and general extent of contamination.

_____ Estimate the variability in the residual radioactivity levels for the site.

_____ Adjust DCGLs based on survey findings (the DCGLs initially selected may not be appropriate for the site).

_____ Determine the need for additional action (*e.g.*, none, remediate, more surveys)

_____ Prepare report for regulatory agency (determine if letter report is sufficient).

5.3 Characterization Surveys

5.3.1 General

Characterization surveys may be performed to satisfy a number of specific objectives. Examples of characterization survey objectives include: 1) determining the nature and extent of radiological contamination, 2) evaluating remediation alternatives (*e.g.*, unrestricted use, restricted use, onsite disposal, off-site disposal, *etc.*), 3) input to pathway analysis/dose or risk assessment models for determining site-specific DCGLs (Bq/kg, Bq/m^2), 4) estimating the occupational and public health and safety impacts during decommissioning, 5) evaluating remediation technologies, 6) input to final status survey design, and 7) Remedial Investigation/Feasibility Study requirements (CERCLA sites only) or RCRA Facility Investigation/Corrective Measures Study requirements (RCRA sites only).

The scope of this manual precludes detailed discussions of characterization survey design for each of these objectives, and therefore, the user should consult other references for specific characterization survey objectives not covered. For example, the *Decommissioning Handbook* (DOE 1994) is a good reference for characterization objectives that are concerned with evaluating remediation technologies or unrestricted/restricted use alternatives. Other references (EPA 1988b, 1988c, 1994a; NRC 1994) should be consulted for planning decommissioning actions, including decontamination techniques, projected schedules, costs, and waste volumes, and health and safety considerations during decontamination. Also, the types of characterization data needed to support risk or dose modeling should be determined from the specific modeling code documentation.

This manual concentrates on providing information for the final status survey design, with limited coverage on determining the specific nature and extent of radionuclide contamination. The specific objectives for providing information to the final status survey design include: 1) estimating the projected radiological status at the time of the final status survey, in terms of radionuclides present, concentration ranges and variances, spatial distribution, *etc.*, 2) evaluating potential reference areas to be used for background measurements, if necessary, 3) reevaluating the initial classification of survey units, 4) selecting instrumentation based on the necessary MDCs, and 5) establishing acceptable Type I and Type II errors with the regulatory agency (Appendix D provides guidance on establishing acceptable decision error rates). Many of these objectives are satisfied by determining the specific nature and extent of contamination of structures, residues, and environmental media. Additional detail on the performance of characterization surveys designed to determine the general extent of contamination can be found in the NRC's *Draft Branch Technical Position on Site Characterization for Decommissioning* (NRC 1994a) and EPA's RI/FS guidance (EPA 1988b; EPA 1993c).

Results of the characterization survey should include: 1) the identification and distribution of contamination in buildings, structures, and other site facilities; 2) the concentration and distribution of contaminants in surface and subsurface soils; 3) the distribution and concentration of contaminants in surface water, ground water, and sediments, and 4) the distribution and concentration of contaminants in other impacted media such as vegetation or paint. The characterization should include sufficient information on the physical characteristics of the site, including surface features, meteorology and climatology, surface water hydrology, geology, demography and land use, and hydrogeology. This survey should also address environmental conditions that could affect the rate and direction of contaminant transport in the environment, depending on the extent of contamination identified above.

The following sections describe a method for planning, conducting, and documenting characterization surveys. Alternative methodologies may also be acceptable to the regulatory agencies.

5.3.2 Survey Design

The design of the site characterization survey is based on the specific DQOs for the information to be collected, and is planned using the HSA and scoping survey results. The DQO Process ensures that an adequate amount of data with sufficient quality are collected for the purpose of characterization. The site characterization process typically begins with a review of the HSA, which includes available information on site description, operational history, and the type and extent of contamination (from the scoping survey, if performed). The site description, or conceptual site model as first developed in Section 3.6.4, consists of the general area, dimensions, and locations of contaminated areas on the site. A site map should show site boundaries, roads, hydrogeologic features, major structures, and other features that could affect decommissioning activities.

The operational history includes records of site conditions prior to operational activities, operational activities of the facility, effluents and on-site disposal, and significant incidents—including spills or other unusual occurrences—involving the spread of contamination around the site and on areas previously released from radiological controls. This review should include other available resources, such as site personnel, former workers, residents, *etc.* Historic aerial photographs and site location maps may be particularly useful in identifying potential areas of contamination.

The types and quantities of materials that were handled and the locations and disposition of radioactive materials should be reviewed using available documentation (*e.g.*, the radioactive materials license). Contamination release and migration pathways should be identified, as well as areas that are potentially affected and are likely to contain residual contamination. The types and quantities of materials likely to remain onsite, considering radioactive decay, should be determined.

The characterization survey should clearly identify those portions of the site (*e.g.*, soil, structures, and water) that have been affected by site activities and are potentially contaminated. The survey should also identify the portions of the site that have not been affected by these activities. In some cases where no remediation is anticipated, results of the characterization survey may indicate compliance with DCGLs established by the regulatory agency. When planning for the potential use of characterization survey data as part of the final status survey, the characterization data must be of sufficient quality and quantity for that use (see Section 5.5). There are several processes that are likely to occur in conjunction with characterization. These include considering and evaluating remediation alternatives, and calculating site-specific DCGLs.

The survey should also provide information on variations in the contaminant distribution in the survey area. The contaminant variation in each survey unit contributes to determining the number of data points based on the statistical tests used during the final status survey (Section 5.5.2). Additionally, characterization data may be used to justify reclassification for some survey units (*e.g.*, from Class 1 to Class 2).

Note that because of site-specific characteristics of contamination, performing all types of measurements described here may not be relevant at every site. For example, detailed characterization data may not be needed for areas with contamination well above the DCGLs that clearly require remediation. Judgment should be used in determining the types of characterization information needed to provide an appropriate basis for decontamination decisions.

5.3.3 Conducting Surveys

Characterization survey activities often involve the detailed assessment of various types of building and environmental media, including building surfaces, surface and subsurface soil, surface water, and ground water. The HSA data should be used to identify the potentially contaminated media onsite (see Section 3.6.3). Identifying the media that may contain contamination is useful for preliminary survey unit classification and for planning subsequent survey activities. Selection of survey instrumentation and analytical techniques are typically based on a knowledge of the appropriate DCGLs, because remediation decisions are made based on the level of the residual contamination as compared to the DCGL. Exposure rate measurements may be needed to assess occupational and public health and safety. The location of underground utilities should be considered before conducting a survey to avoid compounding the problems at the site.

5.3.3.1 Structure Surveys

Surveys of building surfaces and structures include surface scanning, surface activity measurements, exposure rate measurements, and sample collection (*e.g.*, smears, subfloor soil, water, paint, and building materials). Both field survey instrumentation (Chapter 6) and analytical laboratory equipment and procedures (Chapter 7) are selected based on their detection capabilities for the expected contaminants and their quantities. Field and laboratory instruments are described in Appendix H.

Background activity and radiation levels for the area should be determined from appropriate background reference areas. Background assessments include surface activity measurements on building surfaces, exposure rates, and radionuclide concentrations in various media (refer to Section 4.5).

Measurement locations should be documented using reference system coordinates, if appropriate, or fixed site features. A typical reference system spacing for building surfaces is 1 meter. This is chosen to facilitate identifying survey locations, evaluating small areas of elevated activity, and determining survey unit average activity levels.

Scans should be conducted in areas likely to contain residual activity, based on the results of the HSA and scoping survey.

Both systematic and judgment surface activity measurements are performed. Judgment direct measurements are performed at locations of elevated direct radiation, as identified by surface scans, to provide data on upper ranges of residual contamination levels. Judgment measurements may also be performed in sewers, air ducts, storage tanks, septic systems and on roofs of buildings, if necessary. Each surface activity measurement location should be carefully recorded on the appropriate survey form.

Exposure rate measurements and media sampling are performed as necessary. For example, subfloor soil samples may provide information on the horizontal and vertical extent of contamination. Similarly, concrete core samples are necessary to evaluate the depth of activated concrete in a reactor facility. Note that one type of radiological measurement may be sufficient to determine the extent of contamination. For example, surface activity measurements alone may be all that is needed to demonstrate that decontamination of a particular area is necessary; exposure rate measurements would add little to this determination.

Lastly, the measuring and sampling techniques should be commensurate with the intended use of the data, as characterization survey data may be used to supplement final status survey data, provided that the data meet the selected DQOs.

5.3.3.2 Land Area Surveys

Characterization surveys for surface and subsurface soils and media involve employing techniques to determine the lateral and vertical extent and radionuclide concentrations in the soil. This may be performed using either sampling and laboratory analyses, or *in situ* gamma spectrometry analyses, depending on the detection capabilities of each methodology for the expected contaminants and concentrations. Note that *in situ* gamma spectrometry analyses or any direct surface measurement cannot easily be used to determine vertical distributions of radionuclides. Sample collection followed by laboratory analysis introduces several additional sources of uncertainty that need to be considered during survey design. In many cases, a combination of direct measurements and samples is required to meet the objectives of the survey.

Radionuclide concentrations in background soil samples should be determined for a sufficient number of soil samples that are representative of the soil in terms of soil type, soil depth, *etc.* It is important that the background samples be collected in non-impacted areas. Consideration should be given to spatial variations in the background radionuclide concentrations as discussed in Section 4.5 and NRC draft report NUREG-1501 (NRC 1994b).

Sample locations should be documented using reference system coordinates (see Section 4.8.5), if appropriate, or fixed site features. A typical reference system spacing for open land areas is 10 meters (NRC 1992a). This spacing is somewhat arbitrary and is chosen to facilitate determining survey unit locations and evaluating areas of elevated radioactivity.

Surface scans for gamma activity should be conducted in areas likely to contain residual activity. Beta scans may be appropriate if the contamination is near the surface and represents the prominent radiation emitted from the contamination. The sensitivity of the scanning technique should be appropriate to meet the DQOs.

Both surface and subsurface soil and media samples may be necessary. Subsurface soil samples should be collected where surface contamination is present and where subsurface contamination is known or suspected. Boreholes should be constructed to provide samples representing subsurface deposits.

Exposure rate measurements at 1 meter above the sampling location may also be appropriate. Each surface and subsurface soil sampling and measurement location should be carefully recorded.

5.3.3.3 Other Measurements/Sampling Locations

Surface Water and Sediments. Surface water and sediment sampling may be necessary depending on the potential for these media to be contaminated. The contamination potential depends on several factors, including the proximity of surface water bodies to the site, size of the drainage area, total annual rainfall, and spatial and temporal variability in surface water flow rate and volume. Refer to Section 3.6.3.3 for further consideration of the necessity for surface water and sediment sampling.

Characterizing surface water involves techniques that determine the extent and distribution of contaminants. This may be performed by collecting grab samplesof the surface water in a well-mixed zone. At certain sites, it may be necessary to collect stratified water samples to provide information on the vertical distribution of contamination. Sediment sampling should also be performed to assess the relationship between the composition of the suspended sediment and the bedload sediment fractions (*i.e.*, suspended sediments compared to deposited sediments). When judgment sampling is used to find radionuclides in sediments, contaminated sediments are more likely to be accumulated on fine-grained deposits found in low-energy environments (*e.g.*, deposited silt on inner curves of streams).

Radionuclide concentrations in background water samples should be determined for a sufficient number of water samples that are upstream of the site or in areas unaffected by site operations. Consideration should be given to any spatial or temporal variations in the background radionuclide concentrations.

Sampling locations should be documented using reference system coordinates, if appropriate, or scale drawings of the surface water bodies. Effects of variability of surface water flow rate should be considered. Surface scans for gamma activity may be conducted in areas likely to contain residual activity (*e.g.*, along the banks) based on the results of the document review and/or preliminary investigation surveys.

Surface water sampling should be performed in areas of runoff from active operations, at plant outfall locations, both upstream and downstream of the outfall, and any other areas likely to contain residual activity (see Section 3.6.3.3). Measurements of radionuclide concentrations in water should include gross alpha and gross beta assessments, as well as any necessary radionuclide-specific analyses. Non-radiological parameters, such as specific conductance, pH, and total organic carbon may be used as surrogate indicators of potential contamination, provided that a specific relationship exists between the radionuclide concentration and the level of the indicator (*e.g.*, a linear relationship between pH and the radionuclide concentration in water is found to exist, then the pH may be measured such that the radionuclide concentration can be calculated based on the known relationship rather than performing an expensive nuclide-specific analysis). The use of surrogate measurements is discussed in Section 4.3.2.

Each surface water and sediment sampling location should be carefully recorded on the appropriate survey form. Additionally, surface water flow models may be used to illustrate contaminant concentrations and migration rates.

Ground Water. Ground-water sampling may be necessary depending on the local geology, potential for subsurface contamination, and the regulatory framework. Because different agencies handle ground water contamination situations in different ways (*e.g.*, EPA's Superfund program and some States require compliance with maximum contaminant levels specified in the Safe Drinking Water Act), the responsible regulatory agency should be contacted if ground water contamination is expected. The need for ground-water sampling is described in Section 3.6.3.4.

If ground-water contamination is identified, the responsible regulatory agency should be contacted at once because: 1) ground water release criteria and DCGLs should be established by the appropriate agency (Section 4.3), and 2) the default DCGLs for soil may be inappropriate since they are usually based on initially uncontaminated ground water.

Characterization of ground-water contamination should determine the extent and distribution of contaminants, rates and direction of ground water migration, and the assessment of potential effects of ground water withdrawal on the migration of ground water contaminants. This may be performed by designing a suitable monitoring well network. The actual number and location of monitoring wells depends on the size of the contaminated area, the type and extent of the contaminants, the hydrogeologic system, and the objectives of the monitoring program.

When ground-water samples are taken, background should be determined by sufficient sampling and analysis of ground-water samples collected from the same aquifer upgradient of the site. The background samples should not be affected by site operations and should be representative of the quality of the ground water that would exist if the site had not been contaminated. Consideration should be given to any spatial or temporal variations in the background radionuclide concentrations.

Sampling locations should be referenced to grid coordinates, if appropriate, or to scale drawings of the ground-water monitoring wells. Construction specifications on the monitoring wells should also be provided, including elevation, internal and external dimensions, types of casings, type of screen and its location, borehole diameter, and other necessary information on the wells.

In addition to organic and inorganic constituents, ground-water sampling and analyses should include all significant radiological contaminants. Measurements in potential sources of drinking water should include gross alpha and gross beta assessments, as well as any other radionuclide-specific analyses. Non-radiological parameters, such as specific conductance, pH, and total organic carbon may be used as surrogate indicators of potential contamination, provided that a specific relationship exists between the radionuclide concentration and the level of the indicator.

Each ground-water monitoring well location should be carefully recorded on the appropriate survey form. Additionally, contaminant concentrations and sources should be plotted on a map to illustrate the relationship among contamination, sources, hydrogeologic features and boundary conditions, and property boundaries (EPA 1993b).

Other Media. Air sampling may be necessary at some sites depending on the local geology and the radionuclides of potential concern. This may include collecting air samples or filtering the air to collect resuspended particulates. Air sampling is often restricted to monitoring activities for occupational and public health and safety and is not required to demonstrate compliance with risk- or dose-based regulations. Section 3.6.3.5 describes examples of sites where air sampling may provide information useful to designing a final status survey. At some sites, radon measurements may be used to indicate the presence of radium, thorium, or uranium in the soil. Section 6.9 and Appendix H provide information on this type of sampling.

In rare cases, vegetation samples may be collected as part of a characterization survey to provide information in preparation for a final status survey. Because most risk- and dose-based regulations are concerned with potential future land use that may differ from the current land use, vegetation samples are unsuitable for demonstrating compliance with regulations. There is a relationship between radionuclide concentrations in plants and those in soil (the soil-to-plant transfer factor is used in many models to develop DCGLs) and the plant concentration could be used as a surrogate measurement of the soil concentration. In most cases, a measurement of the soil itself as the parameter of interest is more appropriate and introduces less uncertainty in the result.

5.3.4 Evaluating Survey Results

Survey data are converted to the same units as those in which DCGLs are expressed (Section 6.6). Identification of potential radionuclide contaminants at the site is performed through laboratory and *in situ* analyses. Appropriate regulatory DCGLs for the site are selected and the data are then compared to the DCGLs. For characterization data that are used to supplement final status survey data, the statistical methodology in Chapter 8 should be followed to determine if a survey unit satisfies the release criteria.

For characterization data that are used to help guide remediation efforts, the survey data are used to identify locations and general extent of residual activity. The survey results are first compared with DCGLs. Surfaces and environmental media are then differentiated as exceeding DCGLs, not exceeding DCGLs, or not contaminated, depending on the measurement results relative to the DCGL value. Direct measurements indicating areas of elevated activity are further evaluated and the need for additional measurements is determined.

5.3.5 Documentation

Documentation of the site characterization survey should provide a complete and unambiguous record of the radiological status of the site. In addition, sufficient information to characterize the extent of contamination, including all possible affected environmental media, should be provided in the report. This report should also provide sufficient information to support reasonable approaches or alternatives to site decontamination.

EXAMPLE CHARACTERIZATION SURVEY CHECKLIST

SURVEY DESIGN

_____ Enumerate DQOs: State objective of the survey; survey instrumentation capabilities should be appropriate for the specific survey objective.

_____ Review the Historical Site Assessment for:

- _____ Operational history (*e.g.*, any problems, spills, or releases) and available documentation (*e.g.*, radioactive materials license).
- _____ Other available resources—site personnel, former workers, residents, *etc.*
- _____ Types and quantities of materials that were handled and where radioactive materials were stored, handled, and disposed of.
- _____ Release and migration pathways.
- _____ Information on the potential for residual radioactivity that may be useful during area classification for final status survey design. Note: Survey activities will be concentrated in Class 1 and Class 2 areas.
- _____ Types and quantities of materials likely to remain on-site—consider radioactive decay.

CONDUCTING SURVEYS

_____ Select instrumentation based on detection capabilities for the expected contaminants and quantities and a knowledge of the appropriate DCGLs.

_____ Determine background activity and radiation levels for the area; include surface activity levels on building surfaces, radionuclide concentrations in environmental media, and exposure rates.

_____ Establish a reference coordinate system. Prepare scale drawings for surface water and ground-water monitoring well locations.

_____ Perform thorough surface scans of all potentially contaminated areas, *(e.g.*, indoor areas include expansion joints, stress cracks, penetrations into floors and walls for piping, conduit, and anchor bolts, and wall/floor interfaces); outdoor areas include radioactive material storage areas, areas downwind of stack release points, surface drainage pathways, and roadways that may have been used for transport of radioactive or contaminated materials.

_____ Perform systematic surface activity measurements.

_____ Perform systematic smear, surface and subsurface soil and media, sediment, surface water and groundwater sampling, if appropriate for the site.

_____ Perform judgment direct measurements and sampling of areas of elevated activity of residual radioactivity to provide data on upper ranges of residual contamination levels.

_____ Document survey and sampling locations.

_____ Maintain chain of custody of samples when necessary.

Note: One category of radiological data (*e.g.*, radionuclide concentration, direct radiation level, or surface contamination) may be sufficient to determine the extent of contamination; other measurements may not be necessary (*e.g.*, removable surface contamination or exposure rate measurements).

Note: Measuring and sampling techniques should be commensurate with the intended use of the data because characterization survey data may be used to supplement final status survey data.

EVALUATING SURVEY RESULTS

_____ Compare survey results with DCGLs. Differentiate surfaces/areas as exceeding DCGLs, not exceeding DCGLs, or not contaminated.

_____ Evaluate all locations of elevated direct measurements and determine the need for additional measurements/samples.

_____ Prepare site characterization survey report.

5.4 Remedial Action Support Surveys

5.4.1 General

Remedial action support surveys are conducted to 1) support remediation activities, 2) determine when a site or survey unit is ready for the final status survey, and 3) provide updated estimates of site-specific parameters to use for planning the final status survey. This manual does not discuss the routine operational surveys (*e.g.*, air sampling, dose rate measurements, environmental sampling) conducted to support remediation activities.

A remedial action support survey serves to monitor the effectiveness of decontamination efforts that are intended to reduce residual radioactivity to acceptable levels. This type of survey guides the cleanup in a real-time mode. The remedial action support survey typically relies on a simple radiological parameter, such as direct radiation near the surface, as an indicator of effectiveness. The investigation level (the level below which there is an acceptable level of assurance that the established DCGLs have been attained) is determined and used for immediate, in-field decisions (Section 5.5.2.6). Such a survey is intended for expediency and cost effectiveness and does not provide thorough or accurate data describing the radiological status of the site. Note that this survey does not provide information that can be used to demonstrate compliance with the DCGLs and is an interim step in the compliance demonstration process. Areas that are determined to satisfy the DCGLs on the basis of the remedial action support survey will then be surveyed in detail by the final status survey. Alternatively, the remedial action support survey can be designed to meet the objectives of a final status survey as described in Section 5.5. DCGLs may be recalculated based on the results of the remediation process as the regulatory program allows or permits.

Remedial activities result in changes to the distribution of contamination within a survey unit. The site-specific parameters used during final status survey planning (*e.g.*, variability in the radionuclide concentration within a survey unit or probability of small areas of elevated activity) will change during remediation. For most survey units, values for these parameters will need to be re-established following remediation. Obtaining updated values for these critical planning parameters should be considered when designing a remedial action support survey.

5.4.2 Survey Design

The objective of the remedial action support survey is to detect the presence of residual activity at or below the DCGL criteria. Although the presence of small areas of elevated radioactivity may satisfy the elevated measurement criteria, it may be more efficient to design the remedial action support survey to identify residual radioactivity at the $DCGL_W$ (and to remediate small areas of elevated activity that may potentially satisfy the release criteria). Survey instrumentation and techniques are therefore selected based on the detection capabilities for the known or suspected contaminants and DCGLs to be achieved.

There will be radionuclides and media that cannot be evaluated at the $DCGL_W$ using field monitoring techniques. For these cases, it may be feasible to collect and analyze samples by methods that are quicker and less costly than radionuclide-specific laboratory procedures. Field laboratories and screening techniques may be acceptable alternatives to more expensive analyses. Reviewing remediation plans may be required to get an indication of the location and amount of remaining contamination following remediation.

5.4.3 Conducting Surveys

Field survey instruments and procedures are selected based on their detection capabilities for the expected contaminants and their quantities. Survey methods typically include scans of surfaces followed by direct measurements to identify residual radioactivity. The surface activity levels are compared to the DCGLs, and a determination is made on the need for further decontamination efforts.

Survey activities for soil excavations include surface scans using field instrumentation sensitive to beta and gamma activity. Because it is difficult to correlate scanning results to radionuclide concentrations in soil, judgment should be carefully exercised when using scan results to guide the cleanup efforts. Field laboratories and screening techniques may provide a better approach for determining whether or not further soil remediation is necessary.

5.4.4 Evaluating Survey Results

Survey data (*e.g.*, surface activity levels and radionuclide concentrations in various media) are converted to standard units and compared to the DCGLs (Section 6.6). If results of these survey activities indicate that remediation has been successful in meeting the DCGLs, decontamination efforts are ceased and final status survey activities are initiated. Further remediation may be needed if results indicate the presence of residual activity in excess of the DCGLs.

5.4.5 Documentation

The remedial action support survey is intended to guide the cleanup and alert those performing remedial activities that additional remediation is needed or that the site may be ready to initiate a final survey. Data that indicate an area has been successfully remediated could be used to estimate the variance for the survey units in that area. Information identifying areas of elevated activity that existed prior to remediation may be useful for planning final status surveys.

EXAMPLE REMEDIAL ACTION SUPPORT SURVEY CHECKLIST

SURVEY DESIGN

_____ Enumerate DQOs: State the objectives of the survey; survey instrumentation capabilities should be able to detect residual contamination at the DCGL.

_____ Review the remediation plans.

_____ Determine applicability of monitoring surfaces/soils for the radionuclides of concern. Note: Remedial action support surveys may not be feasible for surfaces contaminated with very low energy beta emitters or for soils or media contaminated with pure alpha emitters.

_____ Select simple radiological parameters (*e.g.*, surface activity) that can be used to make immediate in-field decisions on the effectiveness of the remedial action.

CONDUCTING SURVEYS

_____ Select instrumentation based on its detection capabilities for the expected contaminants.

_____ Perform scanning and surface activity measurements near the surface being decontaminated.

_____ Survey soil excavations and perform field evaluation of samples (*e.g.*, gamma spectrometry of undried/non-homogenized soil) as remedial actions progress.

EVALUATING SURVEY RESULTS

_____ Compare survey results with DCGLs using survey data as a field decision tool to guide the remedial actions in a real-time mode.

_____ Document survey results.

5.5 Final Status Surveys

5.5.1 General

A final status survey is performed to demonstrate that residual radioactivity in each survey unit satisfies the predetermined criteria for release for unrestricted use or, where appropriate, for use with designated limitations. The survey provides data to demonstrate that all radiological parameters do not exceed the established DCGLs. For these reasons, more detailed guidance is provided for this category of survey. For the final status survey, survey units represent the fundamental elements for compliance demonstration using the statistical tests (see Section 4.6). The documentation specified in the following sections helps ensure a consistent approach among different organizations and regulatory agencies. This allows for comparisons of survey results between sites or facilities.

This section describes methods for planning and conducting final status surveys to satisfy the objectives of the regulatory agencies. The MARSSIM approach recognizes that alternative methods may be acceptable to those agencies. Flow diagrams and a checklist to assist the user in planning a survey are included in this section.

5.5.2 Survey Design

Figures 5.1 through 5.3 illustrate the process of designing a final status survey. This process begins with development of DQOs. On the basis of these objectives and the known or anticipated radiological conditions at the site, the numbers and locations of measurement and sampling points used to demonstrate compliance with the release criterion are then determined. Finally, survey techniques appropriate to develop adequate data (see Chapters 6 and 7) are selected and implemented.

Planning for the final status survey should include early discussions with the regulatory agency concerning logistics for confirmatory or verification surveys. A confirmatory survey (also known as an independent verification survey), may be performed by the responsible regulatory agency or by an independent third party (*e.g.*, contracted by the regulatory agency) to provide data to substantiate results of the final status survey. Actual field measurements and sampling may be performed. Another purpose of the confirmatory activities may be to identify any deficiencies in the final status survey documentation based on a thorough review of survey procedures and results. Independent confirmatory survey activities are usually limited in scope to spot-checking conditions at selected locations, comparing findings with those of the final status survey, and performing independent statistical evaluations of the data developed from the confirmatory survey and the final status survey.

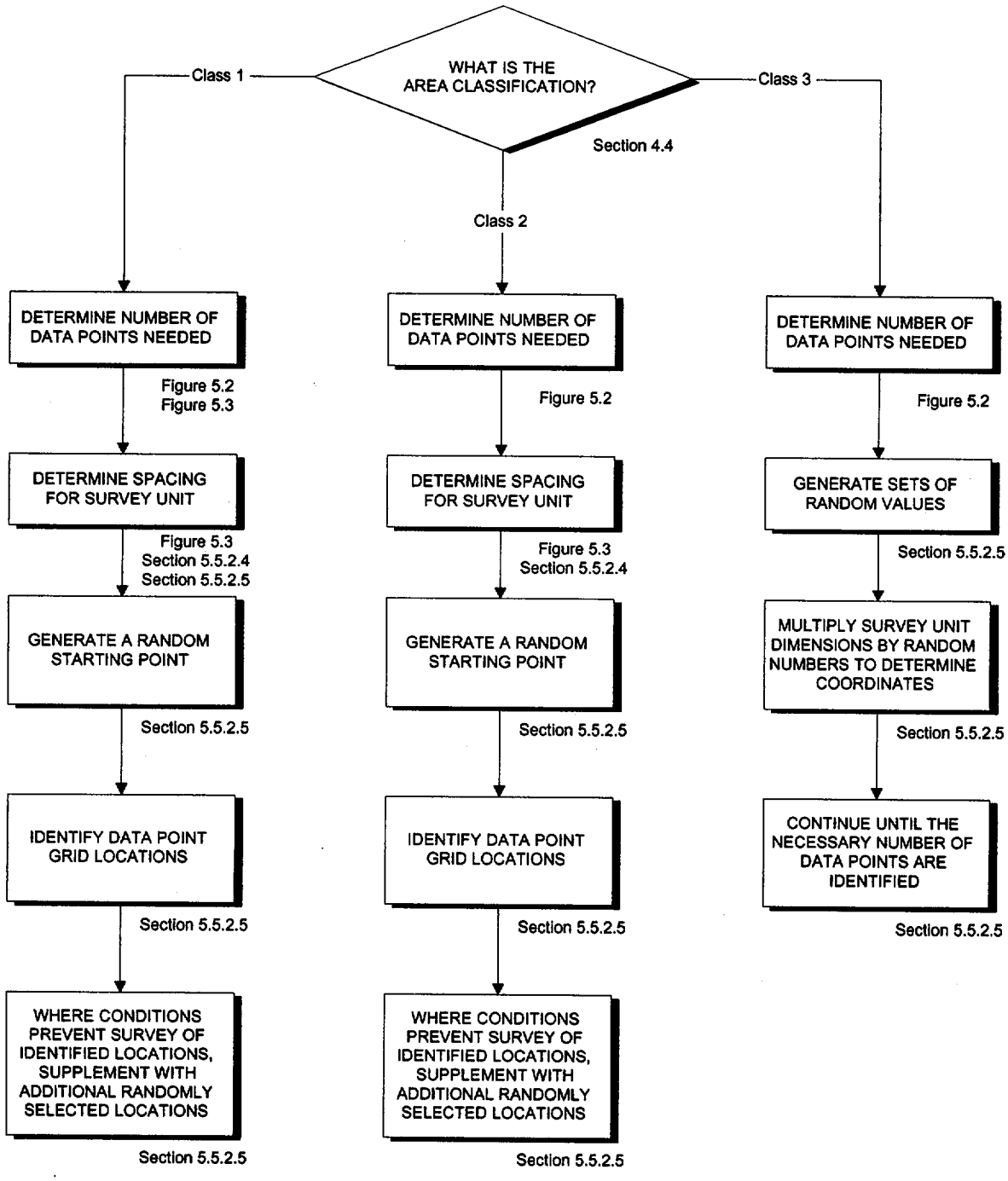


Figure 5.1 Flow Diagram Illustrating the Process for Identifying Measurement Locations (Refer to Section 5.5.2.5)

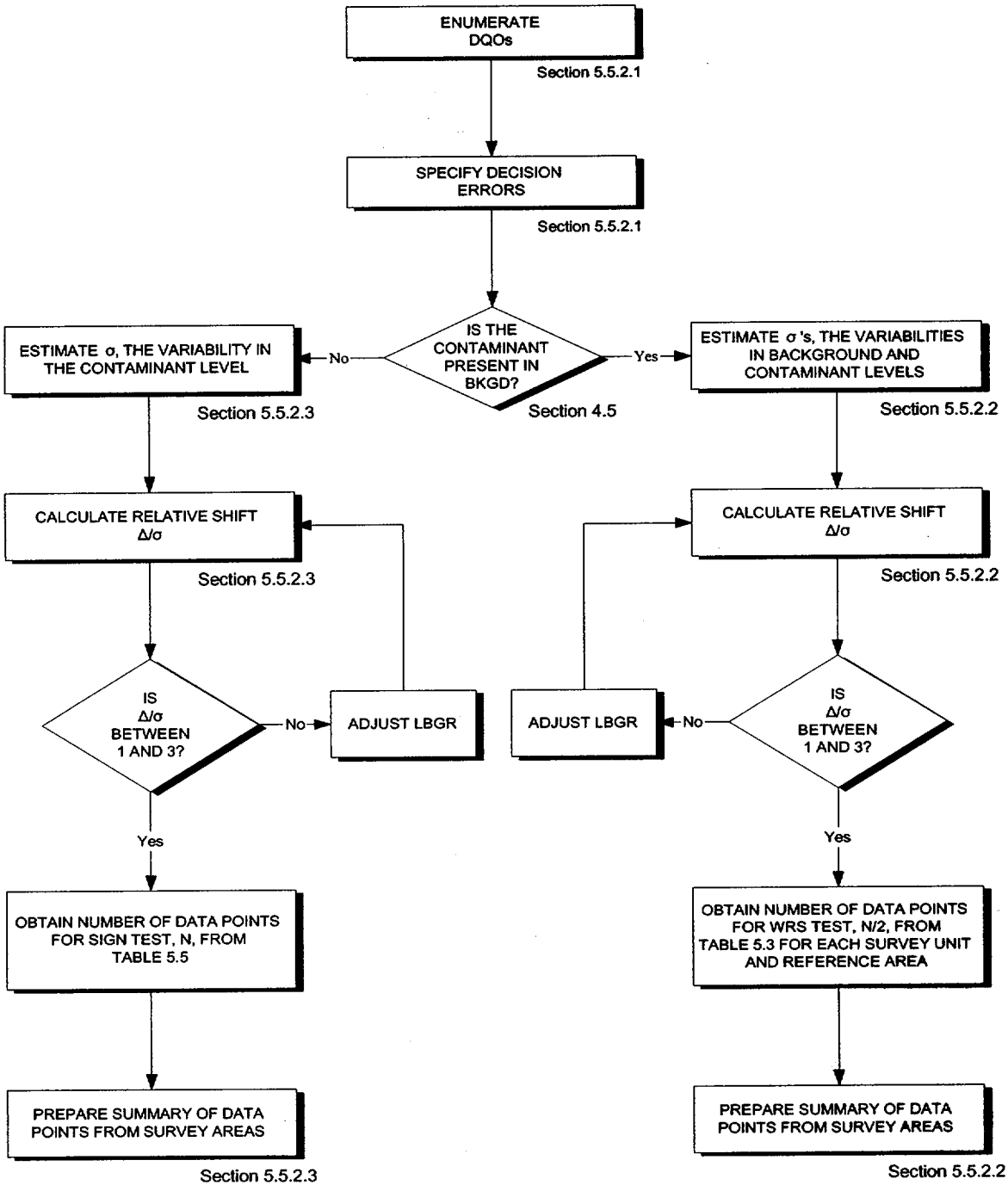


Figure 5.2 Flow Diagram for Identifying the Number of Data Points, N, for Statistical Tests

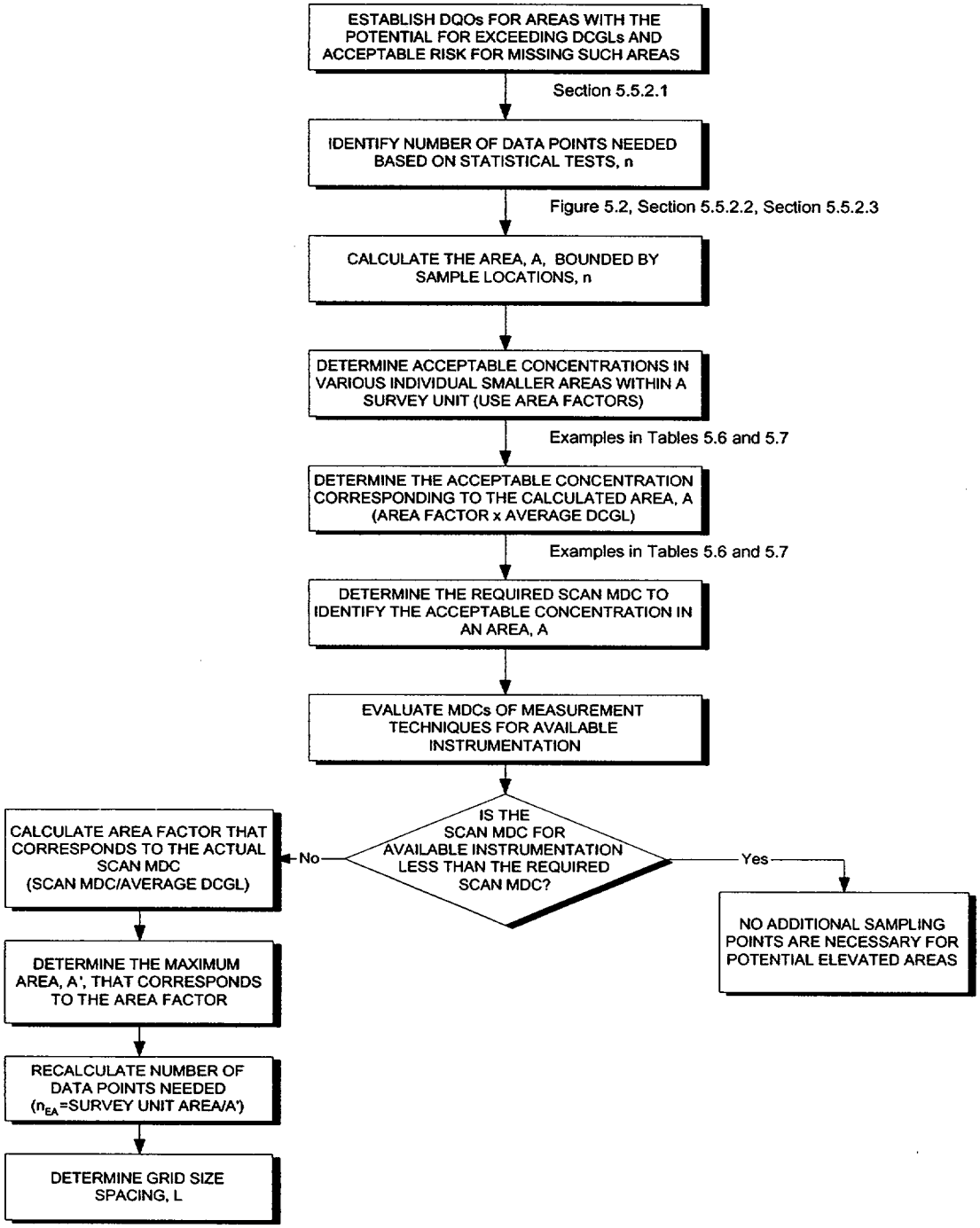


Figure 5.3 Flow Diagram for Identifying Data Needs for Assessment of Potential Areas of Elevated Activity in Class 1 Survey Units (Refer to Section 5.5.2.4)

5.5.2.1 Application of Decommissioning Criteria

The DQO Process, as it is applied to decommissioning surveys, is described in more detail in Appendix D of this manual and in EPA and NRC guidance documents (EPA 1994, 1987b, 1987c; NRC 1997a). As part of this process, the objective of the survey and the null and alternative hypotheses should be clearly stated. The objective of final status surveys is typically to demonstrate that residual radioactivity levels meet the release criterion. In demonstrating that this objective is met, the null hypothesis (H_0) tested is that residual contamination exceeds the release criterion; the alternative hypothesis (H_a) is that residual contamination meets the release criterion.

Two statistical tests are used to evaluate data from final status surveys. For contaminants that are present in background, the Wilcoxon Rank Sum (WRS) test is used. When contaminants are not present in background, the Sign test is used. To determine data needs for these tests, the acceptable probability of making Type I decision errors (α) and Type II decision errors (β) should be established (see Appendix D, Section D.6). The acceptable decision error rates are a function of the amount of residual radioactivity and are determined during survey planning using the DQO Process.

The final step of the DQO process includes selecting the optimal design that satisfies the DQOs. For some sites or survey units, the guidance provided in this section may result in a survey design that cannot be accomplished with the available resources. For these situations, the planning team will need to relax one or more of the constraints used to develop the survey design as described in Appendix D. Examples of survey design constraints discussed in this section include:

- increasing the decision error rates, not forgetting to consider the risks associated with making an incorrect decision
- increasing the width of the gray region by decreasing the lower bound of the gray region
- changing the boundaries—it may be possible to reduce measurement costs by changing or eliminating survey units that may require different decisions

5.5.2.2 Contaminant Present in Background—Determining Numbers of Data Points for Statistical Tests

The comparison of measurements from the reference area and survey unit is made using the WRS test, which should be conducted for each survey unit. In addition, the elevated measurement comparison (EMC) is performed against each measurement to ensure that the measurement result does not exceed a specified investigation level. If any measurement in the remediated survey unit exceeds the specified investigation level, then additional investigation is recommended, at least locally, regardless of the outcome of the WRS test.

The WRS test is most effective when residual radioactivity is uniformly present throughout a survey unit. The test is designed to detect whether or not this activity exceeds the $DCGL_W$. The advantage of this nonparametric test is that it does not assume the data are normally or log-normally distributed. The WRS test also allows for "less than" measurements to be present in the reference area and the survey units. As a general rule, this test can be used with up to 40 % "less than" measurements in either the reference area or the survey unit. However, the use of "less than" values in data reporting is not recommended. Wherever possible, the actual result of a measurement, together with its uncertainty, should be reported.

This section introduces several terms and statistical parameters that will be used to determine the number of data points needed to apply the nonparametric tests. An example is provided to better illustrate the application of these statistical concepts.

Calculate the Relative Shift. The lower bound of the gray region (LBGR) is selected during the DQO Process along with the target values for α and β. The width of the gray region, equal to (DCGL - LBGR), is a parameter that is central to the WRS test. This parameter is also referred to as the shift, Δ. The absolute size of the shift is actually of less importance than the relative shift, Δ/σ, where σ is an estimate of the standard deviation of the measured values in the survey unit. This estimate of σ includes both the real spatial variability in the quantity being measured and the precision of the chosen measurement system. The relative shift, Δ/σ, is an expression of the resolution of the measurements in units of measurement uncertainty.

The shift ($\Delta = DCGL_W$ - LBGR) and the estimated standard deviation in the measurements of the contaminant (σ_r and σ_s) are used to calculate the relative shift, Δ/σ (see Appendix D, Section D.6). The standard deviations in the contaminant level will likely be available from previous survey data (*e.g.*, scoping or characterization survey data for unremediated survey units or remedial action support surveys for remediated survey units). If they are not available, it may be necessary to 1) perform some limited preliminary measurements (about 5 to 20) to estimate the distributions, or 2) to make a reasonable estimate based on available site knowledge. If the first approach above is used, it is important to note that the scoping or characterization survey data or preliminary measurements used to estimate the standard deviation should use the same technique as that to be used during the final status survey. When preliminary data are not obtained, it may be reasonable to assume a coefficient of variation on the order of 30%, based on experience.

The value selected as an estimate of σ for a survey unit may be based on data collected only from within that survey unit or from data collected from a much larger area of the site. Note that survey units are not finalized until the planning stage of the final status survey. This means that there may be some difficulty in determining which individual measurements from a preliminary survey may later represent a particular survey unit. For many sites, the most practical solution is to estimate σ for each area classification (*i.e.*, Class 1, Class 2, and Class 3) for both interior and

exterior survey units. This will result in all exterior Class 3 survey units using the same estimate of σ, all exterior Class 2 survey units using a second estimate for σ, and all exterior Class 1 survey units using a third estimate for σ. If there are multiple types of surfaces within an area classification, additional estimates of σ may be required. For example, a Class 2 concrete floor may require a different estimate of σ than a Class 2 cinder block wall, or a Class 3 unpaved parking area may require a different estimate of σ than a Class 3 lawn. In addition, MARSSIM recommends that a separate estimate of σ be obtained for every reference area.

The importance of choosing appropriate values for σ_r and σ_s must be emphasized. *If the value is grossly underestimated*, the number of data points will be too few to obtain the desired power level for the test and a resurvey may be recommended (refer to Chapter 8). If, on the other hand, *the value is overestimated*, the number of data points determined will be unnecessarily large.

Values for the relative shift that are less than one will result in a large number of measurements needed to demonstrate compliance. The number of data points will also increase as Δ becomes smaller. Since the DCGL is fixed, this means that the lower bound of the gray region also has a significant effect on the estimated number of measurements needed to demonstrate compliance. When the estimated standard deviations in the reference area and survey units are different, the larger value should be used to calculate the relative shift (Δ/σ).

Determine P_r. The probability that a random measurement from the survey unit exceeds a random measurement from the background reference area by less than the $DCGL_W$ when the survey unit median is equal to the LBGR above background is defined as P_r. P_r is used in Equation 5-1 for determining the number of measurements to be performed during the survey. Table 5.1 lists relative shift values and values for P_r. Using the relative shift calculated in the preceding section, the value of P_r can be obtained from Table 5.1. Information on calculating individual values of P_r is available in NUREG-1505 (NRC 1997a).

If the actual value of the relative shift is not listed in Table 5.1, always select the next lower value that appears in the table. For example, Δ/σ=1.67 does not appear in Table 5.1. The next lower value is 1.6, so the value of P_r would be 0.871014.

Determine Decision Error Percentiles. The next step in this process is to determine the percentiles, $Z_{1-\alpha}$ and $Z_{1-\beta}$, represented by the selected decision error levels, α and ß, respectively (see Table 5.2). $Z_{1-\alpha}$ and $Z_{1-\beta}$ are standard statistical values (Harnett 1975).

Table 5.1 Values of P_r for Given Values of the Relative Shift, Δ/σ, when the Contaminant is Present in Background

Δ/σ	P_r	Δ/σ	P_r
0.1	0.528182	1.4	0.838864
0.2	0.556223	1.5	0.855541
0.3	0.583985	1.6	0.871014
0.4	0.611335	1.7	0.885299
0.5	0.638143	1.8	0.898420
0.6	0.664290	1.9	0.910413
0.7	0.689665	2.0	0.921319
0.8	0.714167	2.25	0.944167
0.9	0.737710	2.5	0.961428
1.0	0.760217	2.75	0.974067
1.1	0.781627	3.0	0.983039
1.2	0.801892	3.5	0.993329
1.3	0.820978	4.0	0.997658

If $\Delta/\sigma > 4.0$, use $P_r = 1.000000$

Table 5.2 Percentiles Represented by Selected Values of α and ß

α (or ß)	$Z_{1-\alpha}$ (or $Z_{1-\beta}$)	α (or ß)	$Z_{1-\alpha}$ (or $Z_{1-\beta}$)
0.005	2.576	0.10	1.282
0.01	2.326	0.15	1.036
0.015	2.241	0.20	0.842
0.025	1.960	0.25	0.674
0.05	1.645	0.30	0.524

Calculate Number of Data Points for WRS Test. The number of data points, N, to be obtained from each reference area/survey unit pair for the WRS test is next calculated using

$$N = \frac{(Z_{1-\alpha}+Z_{1-\beta})^2}{3(P_r-0.5)^2} \qquad (5\text{-}1)$$

The value of N calculated using equation 5-1 is an approximation based on estimates of σ and P_r, so there is some uncertainty associated with this calculation. In addition, there will be some missing or unusable data from any survey. The rate of missing or unusable measurements, R, expected to occur in survey units or reference areas and the uncertainty associated with the calculation of N should be accounted for during survey planning. The number of data points should be increased by 20%, and rounded up, over the values calculated using equation 5-1 to obtain sufficient data points to attain the desired power level with the statistical tests and allow for possible lost or unusable data. The value of 20% is selected to account for a reasonable amount of uncertainty in the parameters used to calculate N and still allow flexibility to account for some lost or unusable data. The recommended 20% correction factor should be applied as a minimum value. Experience and site-specific considerations should be used to increase the correction factor if required. If the user determines that the 20% increase in the number of measurements is excessive for a specific site, a retrospective power curve should be used to demonstrate that the survey design provides adequate power to support the decision (see Appendix I).

N is the total number of data points for each survey unit/reference area combination. The N data points are divided between the survey unit, n, and the reference area, m. The simplest method for distributing the N data points is to assign half the data points to the survey unit and half to the reference area, so n=m=N/2. This means that N/2 measurements are performed in each survey unit, and N/2 measurements are performed in each reference area. If more than one survey unit is associated with a particular reference area, N/2 measurements should be performed in each survey unit and N/2 measurements should be performed in the reference area.

Obtain Number of Data Points for WRS Test from Table 5.3. Table 5.3 provides a list of the number of data points used to demonstrate compliance using the WRS test for selected values of α, β, and Δ/σ. The values listed in Table 5.3 represent the number of measurements to be performed in each survey unit as well as in the corresponding reference area. The values were calculated using Equation 5-1 and increased by 20% for the reasons discussed in the previous section.

Example:

A site has 14 survey units and 1 reference area, and the same type of instrument and method is used to perform measurements in each area. The contaminant has a $DCGL_W$ which when converted to cpm equals 160 cpm. The contaminant is present in background at a level of 45 ± 7 (1σ) cpm. The standard deviation of the contaminant in the survey area is ± 20 cpm, based on previous survey results for

Table 5.3 Values of N/2 for Use with the Wilcoxon Rank Sum Test

	α=0.01					α=0.025					α=0.05					α=0.10					α=0.25				
	β					β					β					β					β				
Δ/σ	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25
0.1	5452	4627	3972	3278	2268	4627	3870	3273	2646	1748	3972	3273	2726	2157	1355	3278	2646	2157	1655	964	2268	1748	1355	964	459
0.2	1370	1163	998	824	570	1163	973	823	665	440	998	823	685	542	341	824	665	542	416	243	570	440	341	243	116
0.3	614	521	448	370	256	521	436	369	298	197	448	369	307	243	153	370	298	243	187	109	256	197	153	109	52
0.4	350	297	255	211	146	297	248	210	170	112	255	210	175	139	87	211	170	139	106	62	146	112	87	62	30
0.5	227	193	166	137	95	193	162	137	111	73	166	137	114	90	57	137	111	90	69	41	95	73	57	41	20
0.6	161	137	117	97	67	137	114	97	78	52	117	97	81	64	40	97	78	64	49	29	67	52	40	29	14
0.7	121	103	88	73	51	103	86	73	59	39	88	73	61	48	30	73	59	48	37	22	51	39	30	22	11
0.8	95	81	69	57	40	81	68	57	46	31	69	57	48	38	24	57	46	38	29	17	40	31	24	17	8
0.9	77	66	56	47	32	66	55	46	38	25	56	46	39	31	20	47	38	31	24	14	32	25	20	14	7
1.0	64	55	47	39	27	55	46	39	32	21	47	39	32	26	16	39	32	26	20	12	27	21	16	12	6
1.1	55	47	40	33	23	47	39	33	27	18	40	33	28	22	14	33	27	22	17	10	23	18	14	10	5
1.2	48	41	35	29	20	41	34	29	24	16	35	29	24	19	12	29	24	19	15	9	20	16	12	9	4
1.3	43	36	31	26	18	36	30	26	21	14	31	26	22	17	11	26	21	17	13	8	18	14	11	8	4
1.4	38	32	28	23	16	32	27	23	19	13	28	23	19	15	10	23	19	15	12	7	16	13	10	7	4
1.5	35	30	25	21	15	30	25	21	17	11	25	21	18	14	9	21	17	14	11	7	15	11	9	7	3
1.6	32	27	23	19	14	27	23	19	16	11	23	19	16	13	8	19	16	13	10	6	14	11	8	6	3
1.7	30	25	22	18	13	25	21	18	15	10	22	18	15	12	8	18	15	12	9	6	13	10	8	6	3
1.8	28	24	20	17	12	24	20	17	14	9	20	17	14	11	7	17	14	11	9	5	12	9	7	5	3
1.9	26	22	19	16	11	22	19	16	13	9	19	16	13	11	7	16	13	11	8	5	11	9	7	5	3
2.0	25	21	18	15	11	21	18	15	12	8	18	15	13	10	7	15	12	10	8	5	11	8	7	5	3
2.25	22	19	16	14	10	19	16	14	11	8	16	14	11	9	6	14	11	9	7	4	10	8	6	4	2
2.5	21	18	15	13	9	18	15	13	10	7	15	13	11	9	6	13	10	9	7	4	9	7	6	4	2
2.75	20	17	15	12	9	17	14	12	10	7	15	12	10	8	5	12	10	8	6	4	9	7	5	4	2
3.0	19	16	14	12	8	16	14	12	10	6	14	12	10	8	5	12	10	8	6	4	8	6	5	4	2
3.5	18	16	13	11	8	16	13	11	9	6	13	11	9	8	5	11	9	8	6	4	8	6	5	4	2
4.0	18	15	13	11	8	15	13	11	9	6	13	11	9	7	5	11	9	7	6	4	8	6	5	4	2

the same or similar contaminant distribution. When the estimated standard deviation in the reference area and the survey units are different, the larger value, 20 cpm in this example, should be used to calculate the relative shift. During the DQO process the LBGR is selected to be one-half the $DCGL_W$ (80 cpm) as an arbitrary starting point for developing an acceptable survey design,[1] and Type I and Type II error values (α and β) of 0.05 have been selected. Determine the number of data points to be obtained from the reference area and from each of the survey units for the statistical tests.

The value of the relative shift for the reference area, Δ/σ, is (160-80)/20 or 4. From Table 5.1, the value of P_r is 0.997658. Values of percentiles, represented by the selected decision error levels, are obtained from Table 5.2. In this case $Z_{1-\alpha}$ (for $\alpha = 0.05$) is 1.645 and $Z_{1-\beta}$ ($\beta = 0.05$) is also 1.645.

The number of data points, N, for the WRS test of each combination of reference area and survey units can be calculated using Equation 5-1

$$N = \frac{(1.645+1.645)^2}{3(0.997658-0.5)^2} = 14.6$$

Adding an additional 20% gives 17.5 which is then rounded up to the next even number, 18. This yields 9 data points for the reference area and 9 for each survey unit.

Alternatively, the number of data points can be obtained directly from Table 5.3. For α=0.05, β=0.05, and Δ/σ=4.0 a value of 9 is obtained for N/2. The table value has already been increased by 20% to account for missing or unusable data.

5.5.2.3 Contaminant Not Present in Background—Determining Numbers of Data Points for Statistical Tests

For the situation where the contaminant is not present in background or is present at such a small fraction of the $DCGL_W$ as to be considered insignificant, a background reference area is not necessary. Instead, the contaminant levels are compared directly with the DCGL value. The general approach closely parallels that used for the situation when the contaminant is present in background as described in Section 5.5.2.2. However, the statistical tests differ slightly. The one-sample Sign test replaces the two-sample Wilcoxon Rank Sum test described above.

[1] Appendix D provides more detailed guidance on the selection of the LBGR.

Calculate the Relative Shift. The initial step in determining the number of data points in the one-sample case is to calculate the relative shift, $\Delta/\sigma_s = (DCGL-LBGR)/\sigma_s$, from the DCGL value, the lower bound of the gray region (LBGR), and the standard deviation of the contaminant in the survey unit, σ_s, as described in Section 5.5.2.2. Also as described in Section 5.5.2.2, the value of σ_s may be obtained from earlier surveys, limited preliminary measurements, or a reasonable estimate. Values of the relative shift that are less than one will result in a large number of measurements needed to demonstrate compliance.

Determine Sign p. Sign p is the estimated probability that a random measurement from the survey unit will be less than the $DCGL_W$ when the survey unit median is actually at the LBGR. The Sign p is used to calculate the minimum number of data points necessary for the survey to meet the DQOs. The value of the relative shift calculated in the previous section is used to obtain the corresponding value of Sign p from Table 5.4.

Table 5.4 Values of Sign p for Given Values of the Relative Shift, Δ/σ, when the Contaminant is Not Present in Background

Δ/σ	Sign p	Δ/σ	Sign p
0.1	0.539828	1.2	0.884930
0.2	0.579260	1.3	0.903199
0.3	0.617911	1.4	0.919243
0.4	0.655422	1.5	0.933193
0.5	0.691462	1.6	0.945201
0.6	0.725747	1.7	0.955435
0.7	0.758036	1.8	0.964070
0.8	0.788145	1.9	0.971284
0.9	0.815940	2.0	0.977250
1.0	0.841345	2.5	0.993790
1.1	0.864334	3.0	0.998650

If $\Delta/\sigma > 3.0$, use Sign p = 1.000000

Determine Decision Error Percentiles. The next step in this process is to determine the percentiles, $Z_{1-\alpha}$ and $Z_{1-\beta}$, represented by the selected decision error levels, α and ß, respectively (see Table 5.2).

Calculate Number of Data Points for Sign Test. The number of data points, N, to be obtained for the Sign test is next calculated using the following formula:

$$N = \frac{(Z_{1-\alpha} + Z_{1-\beta})^2}{4(Sign\ p - 0.5)^2} \qquad 5\text{-}2$$

Finally, the number of anticipated data points should be increased by at least 20% as discussed in Section 5.5.2.2 to ensure sufficient power of the tests and to allow for possible data losses.

Obtain Number of Data Points for Sign Test from Table 5.5. Table 5.5 provides a list of the number of data points used to demonstrate compliance using the Sign test for selected values of α, β, and Δ/σ. The values listed in Table 5.5 represent the number of measurements to be performed in each survey unit. These values were calculated using Equation 5-2 and increased by 20% to account for missing or unusable data and uncertainty in the calculated value of N.

Example:

A site has 1 survey unit. The DCGL level for the contaminant of interest is 140 Bq/kg (3.9 pCi/g) in soil. The contaminant is not present in background; data from previous investigations indicate average residual contamination at the survey unit of 3.7 ± 3.7 (1σ) Bq/kg. The lower bound of the gray region was selected to be 110 Bq/kg. A value of 0.05 is next selected for the probability of Type I decision errors (α) and a value of 0.01 is selected for the probability of Type II decision errors (β) based on the survey objectives. Determine the number of data points to be obtained from the survey unit for the statistical tests.

The value of the shift parameter, Δ/σ, is (140-110)/3.7 or 8. From Table 5.4, the value of Sign p is 1.0. Since Δ/σ>3, the width of the gray region can be reduced. If the LBGR is raised to 125, then Δ/σ is (140-125)/3.7 or 4. The value of Sign p remains at 1.0. Thus, the number of data points calculated will not change. The probability of a Type II error is now specified at 125 Bq/kg (3.4 pCi/g) rather than 110 Bq/kg (3.0 pCi/g). As a consequence, the probability of a Type II error at 110 Bq/kg (3.0 pCi/g) will be even smaller.

Values of percentiles, represented by the selected decision error levels are obtained from Table 5.2. $Z_{1-\alpha}$ (for $\alpha = 0.05$) is 1.645, and $Z_{1-\beta}$ ($\beta = 0.01$) is 2.326.

Table 5.5 Values of N for Use with the Sign Test

	α=0.01					α=0.025					α=0.05					α=0.10					α=0.25				
	β					β					β					β					β				
Δ/σ	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25
0.1	4095	3476	2984	2463	1704	3476	2907	2459	1989	1313	2984	2459	2048	1620	1018	2463	1989	1620	1244	725	1704	1313	1018	725	345
0.2	1035	879	754	623	431	879	735	622	503	333	754	622	518	410	258	623	503	410	315	184	431	333	258	184	88
0.3	468	398	341	282	195	398	333	281	227	150	341	281	234	185	117	282	227	185	143	83	195	150	117	83	40
0.4	270	230	197	162	113	230	1921	162	131	87	197	162	136	107	68	162	131	107	82	48	113	87	68	48	23
0.5	178	152	130	107	75	152	126	107	87	58	130	107	89	71	45	107	87	71	54	33	75	58	45	33	16
0.6	129	110	94	77	54	110	92	77	63	42	94	77	65	52	33	77	63	52	40	23	54	42	33	23	11
0.7	99	83	72	59	41	83	70	59	48	33	72	59	50	40	26	59	48	40	30	18	41	33	26	18	9
0.8	80	68	58	48	34	68	57	48	39	26	58	48	40	32	21	48	39	32	24	15	34	26	21	15	8
0.9	66	57	48	40	28	57	47	40	33	22	48	40	34	27	17	40	33	27	21	12	28	22	17	12	6
1.0	57	48	41	34	24	48	40	34	28	18	41	34	29	23	15	34	28	23	18	11	24	18	15	11	5
1.1	50	42	36	30	21	42	35	30	24	17	36	30	26	21	14	30	24	21	16	10	21	17	14	10	5
1.2	45	38	33	27	20	38	32	27	22	15	33	27	23	18	12	27	22	18	15	9	20	15	12	9	5
1.3	41	35	30	26	17	35	29	24	21	14	30	24	21	17	11	26	21	17	14	8	17	14	11	8	4
1.4	38	33	28	23	16	33	27	23	18	12	28	23	20	16	10	23	18	16	12	8	16	12	10	8	4
1.5	35	30	27	22	15	30	26	22	17	12	27	22	18	15	10	22	17	15	11	8	15	12	10	8	4
1.6	34	29	24	21	15	29	24	21	17	11	24	21	17	14	9	21	17	14	11	6	15	11	9	6	4
1.7	33	28	24	20	14	28	23	20	16	11	24	20	17	14	9	20	16	14	10	6	14	11	9	6	4
1.8	32	27	23	20	14	27	22	20	16	11	23	20	16	12	9	20	16	12	10	6	14	11	9	6	4
1.9	30	26	22	18	14	26	22	18	15	10	22	18	16	12	9	18	15	12	10	6	14	10	9	6	4
2.0	29	26	22	18	12	26	21	18	15	10	22	18	15	12	8	18	15	12	10	6	12	10	8	6	3
2.5	28	23	21	17	12	23	20	17	14	10	21	17	15	11	8	17	14	11	9	5	12	10	8	5	3
3.0	27	23	20	17	12	23	20	17	14	9	20	17	14	11	8	17	14	11	9	5	12	9	8	5	3

The number of data points, N, for the Sign test can be calculated using Equation 5-2.

$$N = \frac{(1.645+2.326)^2}{4(1.0-0.5)^2} = 15.85$$

Adding an additional 20% gives 19.2 and rounding up yields 20 data points for the survey unit.

Alternatively, the number of data points can be obtained directly from Table 5.5. For α=0.05, β=0.01, and Δ/σ>3.0 a value of 20 is obtained for N. The table value has already been increased by 20% to account for missing or unusable data and uncertainty in the calculated value of N.

5.5.2.4 Determining Data Points for Small Areas of Elevated Activity

The statistical tests described above (also see Chapter 8) evaluate whether or not the residual radioactivity in an area exceeds the $DCGL_W$ for contamination conditions that are approximately uniform across the survey unit. In addition, there should be a reasonable level of assurance that any small areas of elevated residual radioactivity that could be significant relative to the $DCGL_{EMC}$ are not missed during the final status survey. The statistical tests introduced in the previous sections may not successfully detect small areas of elevated contamination. Instead, systematic measurements and sampling, in conjunction with surface scanning, are used to obtain adequate assurance that small areas of elevated radioactivity will still satisfy the release criterion or the $DCGL_{EMC}$. The procedure is applicable for all radionuclides, regardless of whether or not they are present in background, and is implemented for survey units classified as Class 1.

The number of survey data points needed for the statistical tests discussed in Section 5.5.2.2 or 5.5.2.3 is identified (the appropriate section depends on whether the contaminant is present in background or not). These data points are then positioned throughout the survey unit by first randomly selecting a start point and establishing a systematic pattern. This systematic sampling grid may be either triangular or square. The triangular grid is generally more efficient for locating small areas of elevated activity. Appendix D includes a brief discussion on the efficiency of triangular and square grids for locating areas of elevated activity. A more detailed discussion is provided by EPA (EPA 1994b).

The number of calculated survey locations, n, is used to determine the grid spacing, L, of the systematic sampling pattern (see Section 5.5.2.5). The grid area that is bounded by these survey locations is given by $A = 0.866 \times L^2$ for a triangular grid and $A = L^2$ for a square grid. The risk of not sampling a circular area—equal to A—of elevated activity by use of a random-start grid pattern is illustrated in Figure D.7 in Appendix D.

One method for determining values for the $DCGL_{EMC}$ is to modify the $DCGL_w$ using a correction factor that accounts for the difference in area and the resulting change in dose or risk. The area factor is the magnitude by which the concentration within the small area of elevated activity can exceed $DCGL_W$ while maintaining compliance with the release criterion. The area factor is determined based on specific regulatory agency guidance.

Tables 5.6 and 5.7 provide examples of area factors generated using exposure pathway models. The outdoor area factors listed in Table 5.6 were calculated using RESRAD 5.6. For each radionuclide, all exposure pathways were calculated assuming a concentration of 37 Bq/kg (1 pCi/g). The area of contamination in RESRAD 5.6 defaults to 10,000 m^2. Other than changing the area (*i.e.*, 1, 3, 10, 30, 100, 300, 1,000, or 3,000 m^2), the RESRAD default values were not changed. The area factors were then computed by taking the ratio of the dose or risk per unit concentration generated by RESRAD for the default 10,000 m^2 to that generated for the other areas listed. If the DCGL for residual radioactivity distributed over 10,000 m^2 is multiplied by this value, the resulting concentration distributed over the specified smaller area delivers the same calculated dose. The indoor area factors listed in Table 5.7 were calculated in a similar manner using RESRAD-BUILD 1.5. For each radionuclide, all exposure pathways were calculated assuming a concentration of 37 Bq/m^2 (1 pCi/m^2). The area of contamination in RESRAD-BUILD 1.5 defaults to 36 m^2. The other areas compared to this value were 1, 4, 9, 16, or 25 m^2. Removable surface contamination was assumed to be 10%. No other changes to the default values were made. Note that the use of RESRAD to determine area factors is for illustration purposes only. The MARSSIM user should consult with the responsible regulatory agency for guidance on acceptable techniques to determine area factors.

The minimum detectable concentration (MDC) of the scan procedure—needed to detect an area of elevated activity at the limit determined by the area factor—is calculated as follows:

$$Scan\ MDC\ (required) = (DCGL_W) \times (Area\ Factor) \qquad 5\text{-}3$$

The actual MDCs of scanning techniques are then determined for the available instrumentation (see Section 6.7). The actual MDC of the selected scanning technique is compared to the required scan MDC. If the actual scan MDC is less than the required scan MDC, no additional sampling points are necessary for assessment of small areas of elevated activity. In other words, the scanning technique exhibits adequate sensitivity to detect small areas of elevated activity.

Table 5.6 Illustrative Examples of Outdoor Area Dose Factors*

Nuclide	Area Factor								
	1 m^2	3 m^2	10 m^2	30 m^2	100 m^2	300 m^2	1000 m^2	3000 m^2	10000 m^2
Am-241	208.7	139.7	96.3	44.2	13.4	4.4	1.3	1.0	1.0
Co-60	9.8	4.4	2.1	1.5	1.2	1.1	1.1	1.0	1.0
Cs-137	11.0	5.0	2.4	1.7	1.4	1.3	1.1	1.1	1.0
Ni-63	1175.2	463.7	154.8	54.2	16.6	5.6	1.7	1.5	1.0
Ra-226	54.8	21.3	7.8	3.2	1.1	1.1	1.0	1.0	1.0
Th-232	12.5	6.2	3.2	2.3	1.8	1.5	1.1	1.0	1.0
U-238	30.6	18.3	11.1	8.4	6.7	4.4	1.3	1.0	1.0

* The values listed in Table 5.6 are for illustrative purposes only. Consult regulatory guidance to determine area factors to be used for compliance demonstration.

Table 5.7 Illustrative Examples of Indoor Area Dose Factors*

Nuclide	Area Factor					
	1 m^2	4 m^2	9 m^2	16 m^2	25 m^2	36 m^2
Am-241	36.0	9.0	4.0	2.2	1.4	1.0
Co-60	9.2	3.1	1.9	1.4	1.2	1.0
Cs-137	9.4	3.2	1.9	1.4	1.2	1.0
Ni-63	36.0	9.0	4.0	2.3	1.4	1.0
Ra-226	18.1	5.5	2.9	1.9	1.3	1.0
Th-232	36.0	9.0	4.0	2.2	1.4	1.0
U-238	35.7	9.0	4.0	2.2	1.4	1.0

* The values listed in Table 5.7 are for illustrative purposes only. Consult regulatory guidance to determine area factors to be used for compliance demonstration.

If the actual scan MDC is greater than the required scan MDC (*i.e.*, the available scan sensitivity is not sufficient to detect small areas of elevated activity), then it is necessary to calculate the area factor that corresponds to the actual scan MDC:

$$Area\ Factor = \frac{scan\ MDC\ (actual)}{DCGL} \qquad 5\text{-}4$$

The size of the area of elevated activity (in m^2) that corresponds to this area factor is then obtained from specific regulatory agency guidance, and may be similar to those illustrated in Table 5.6 or Table 5.7. The data needs for assessing small areas of elevated activity can then be determined by dividing the area of elevated activity acceptable to the regulatory agency into the survey unit area. For example, if the area of elevated activity is 100 m^2 (from Table 5.6) and the survey unit area is 2,000 m^2, then the calculated number of survey locations is 20. The calculated number of survey locations, n_{EA}, is used to determine a revised spacing, L, of the systematic pattern (refer to Section 5.5.2.5). Specifically, the spacing, L, of the pattern (when driven by the areas of elevated activity) is given by:

$$L = \sqrt{\frac{A}{0.866\ n_{EA}}}\quad for\ a\ triangular\ grid \qquad 5\text{-}5$$

$$L = \sqrt{\frac{A}{n_{EA}}}\quad for\ a\ square\ grid \qquad 5\text{-}6$$

where A is the area of the survey unit. Grid spacings should generally be rounded *down* to the nearest distance that can be conveniently measured in the field.

If the number of data points required to identify areas of elevated activity (n_{EA}) is greater than the number of data points calculated using Equation 5-1 (N/2) or Equation 5-2 (N), L should be calculated using Equation 5-5 or Equation 5-6. This value of L is then used to determine the measurement locations as described in Section 5.5.2.5. If n_{EA} is smaller than N/2 or N, L is calculated using Equation 5-7 or Equation 5-8 as described in Section 5.5.2.5. The statistical tests are performed using this larger number of data points. Figure 5.3 provides a concise overview of the procedure used to identify data needs for the assessment of small areas of elevated activity. If residual radioactivity is found in an isolated area of elevated activity—in addition to residual radioactivity distributed relatively uniformly across the survey unit—the unity rule (described in Section 4.3.3) can be used to ensure that the total dose or risk does not exceed the release criterion (see Section 8.5.2). If there is more than one elevated area, a separate term should be included for each. As an alternative to the unity rule, the dose or risk due to the actual residual radioactivity distribution can be calculated if there is an appropriate exposure pathway model available. Note that these considerations generally apply only to Class 1 survey units, since areas of elevated activity should not exist in Class 2 or Class 3 survey units.

When the detection limit of the scanning technique is very large relative to the $DCGL_{EMC}$, the number of measurements estimated to demonstrate compliance using the statistical tests may become unreasonably large. In this situation perform an evaluation of the survey objectives and considerations. These considerations may include the survey design and measurement methodology, exposure pathway modeling assumptions and parameter values used to determine the DCGLs, Historical Site Assessment conclusions concerning source terms and radionuclide distributions, and the results of scoping and characterization surveys. In most cases the result of this evaluation is not expected to justify an unreasonably large number of measurements.

Example 1:

A Class 1 land area survey unit of 1,500 m^2 is potentially contaminated with ^{60}Co. The $DCGL_W$ value for ^{60}Co is 110 Bq/kg (3 pCi/g) and the scan sensitivity for this radionuclide has been determined to be 150 Bq/kg (4 pCi/g). Calculations indicate the number of data points needed for statistical testing is 27. The distance between measurement locations for this number of data points and the given land area is 8 m. The area encompassed by a triangular sampling pattern of 8 m is approximately 55.4 m^2. From Table 5.6 an area factor of about 1.4 is determined by interpolation. The acceptable concentration in a 55.4 m^2 area is therefore 160 Bq/kg (1.4 × 110 Bq/kg). Since the scan sensitivity of the procedure to be used is less than the $DCGL_W$ times the area factor, no additional data points are needed to demonstrate compliance with the elevated measurement comparison criteria.

Example 2:

A Class 1 land area survey unit of 1500 m^2 is potentially contaminated with ^{60}Co. The DCGL for ^{60}Co is 110 Bq/kg (3 pCi/g). In contrast to Example 1, the scan sensitivity for this radionuclide has been determined to be 170 Bq/kg (4.6 pCi/g). Calculations indicate the number of data points needed for statistical testing is 15. The distance between measurement locations for this number of data points and land area is 10 m. The area encompassed by a triangular sampling pattern of 10 m is approximately 86.6 m^2. From Table 5.6 an area factor of about 1.3 is determined by interpolation. The acceptable concentration in a 86.6 m^2 area is therefore 140 Bq/kg (1.3 × 110 Bq/kg). Since the scan sensitivity of the procedure to be used is greater than the $DCGL_W$ times the area factor, the data points obtained for the statistical testing may not be sufficient to demonstrate compliance using the elevated measurement comparison. The area multiplier for elevated activity that would have to be achieved is 1.5 (170/110 Bq/kg). This is equivalent to an area of 30 m^2 (Table 5.6) which would be obtained with a spacing of about 6 m. A triangular pattern of 6 m spacing includes 50 data points, so 50 measurements should be performed in the survey unit.

5.5.2.5 Determining Survey Locations

A scale drawing of the survey unit is prepared, along with the overlying planar reference coordinate system or grid system. Any location within the survey area is thus identifiable by a unique set of coordinates. The maximum length, X, and width, Y, dimensions of the survey unit are then determined. Identifying and documenting a specific location for each measurement performed is an important part of a final status survey to ensure that measurements can be reproduced if necessary. The reference coordinate system described in Section 4.8.5 provides a method for relating measurements to a specific location within a survey unit.

If the same values for α, β, and Δ/σ are used in Equations 5-1 or Equation 5-2, the required number of measurements is independent of survey unit classification. This means that the same number of measurements could be performed in a Class 1, Class 2, or Class 3 survey unit. While this is a best case scenario, it points out the importance of identifying appropriate survey units (*e.g.*, size, classification) in defining the level of survey effort. The spacing of measurements is affected by the number of measurements, which is independent of classification. However, the spacing of measurements is also affected by survey unit area, the variability in the contaminant concentration, and the interface with the models used to develop the DCGLs which are dependent on classification.

Land Areas. Measurements and samples in Class 3 survey units and reference areas should be taken at random locations. These locations are determined by generating sets of random numbers (2 values, representing the X axis and Y axis distances). Random numbers can be generated by calculator or computer, or can be obtained from mathematical tables. Sufficient sets of numbers will be needed to identify the total number of survey locations established for the survey unit. Each set of random numbers is multiplied by the appropriate survey unit dimension to provide coordinates, relative to the origin of the survey unit reference grid pattern. Coordinates identified in this manner, which do not fall within the survey until area or which cannot be surveyed, due to site conditions, are replaced with other survey points determined in the same manner. Figure 5.4 is an example of a random sampling pattern. In this example, 8 data points were identified using the appropriate formula based on the statistical tests (*i.e.*, Equation 5-1 or Equation 5-2). The locations of these points were determined using the table of random numbers found in Appendix I, Table I.6.

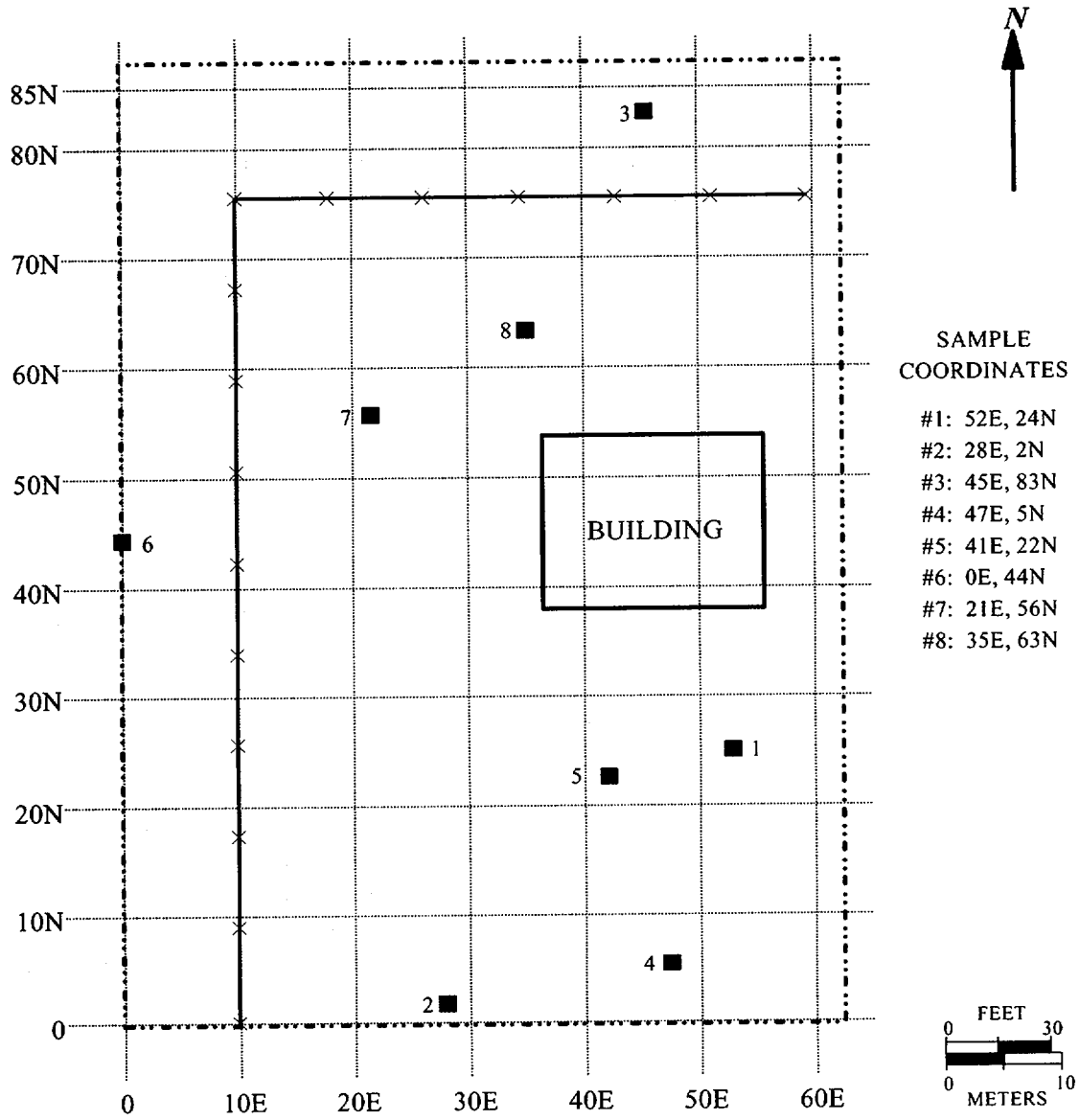


Figure 5.4 Example of a Random Measurement Pattern

Class 2 areas are surveyed on a random-start systematic pattern. The number of calculated survey locations, n, based on the statistical tests, is used to determine the spacing, L, of a systematic pattern by:

$$L = \sqrt{\frac{A}{0.866\ n}} \quad \textit{for a triangular grid} \qquad 5\text{-}7$$

$$L = \sqrt{\frac{A}{n}} \quad \textit{for a square grid} \qquad 5\text{-}8$$

where A is the area of the survey unit.

After L is determined, a random coordinate location is identified, as described previously, for a survey pattern starting location. Beginning at the random starting coordinate, a row of points is identified, parallel to the X axis, at intervals of L.

For a triangular grid, a second row of points is then developed, parallel to the first row, at a distance of 0.866 × L from the first row. Survey points along that second row are midway (on the X-axis) between the points on the first row. This process is repeated to identify a pattern of survey locations throughout the affected survey unit. If identified points fall outside the survey unit or at locations which cannot be surveyed, additional points are determined using the random process described above, until the desired total number of points is identified.

An example of such a survey pattern is shown in Figure 5.5. In this example, the statistical test calculations estimate 20 samples (Table 5.5, α=0.01, β=0.05, Δ/σ>3.0). The random-start coordinate was 27E, 53N. The grid spacing was calculated using Equation 5-7:

$$L = \sqrt{\frac{5{,}100\ m^2}{0.866 \times 20}} = 17\ m.$$

Two points were identified on a row parallel to the X-axis, each 17 m from the starting point. The subsequent rows were positioned 0.866 × L, or 15 m, from the initial row. This random-start triangular sampling process resulted in 21 sampling locations, one of which was inaccessible because of the building location, which yields the desired number of data points.

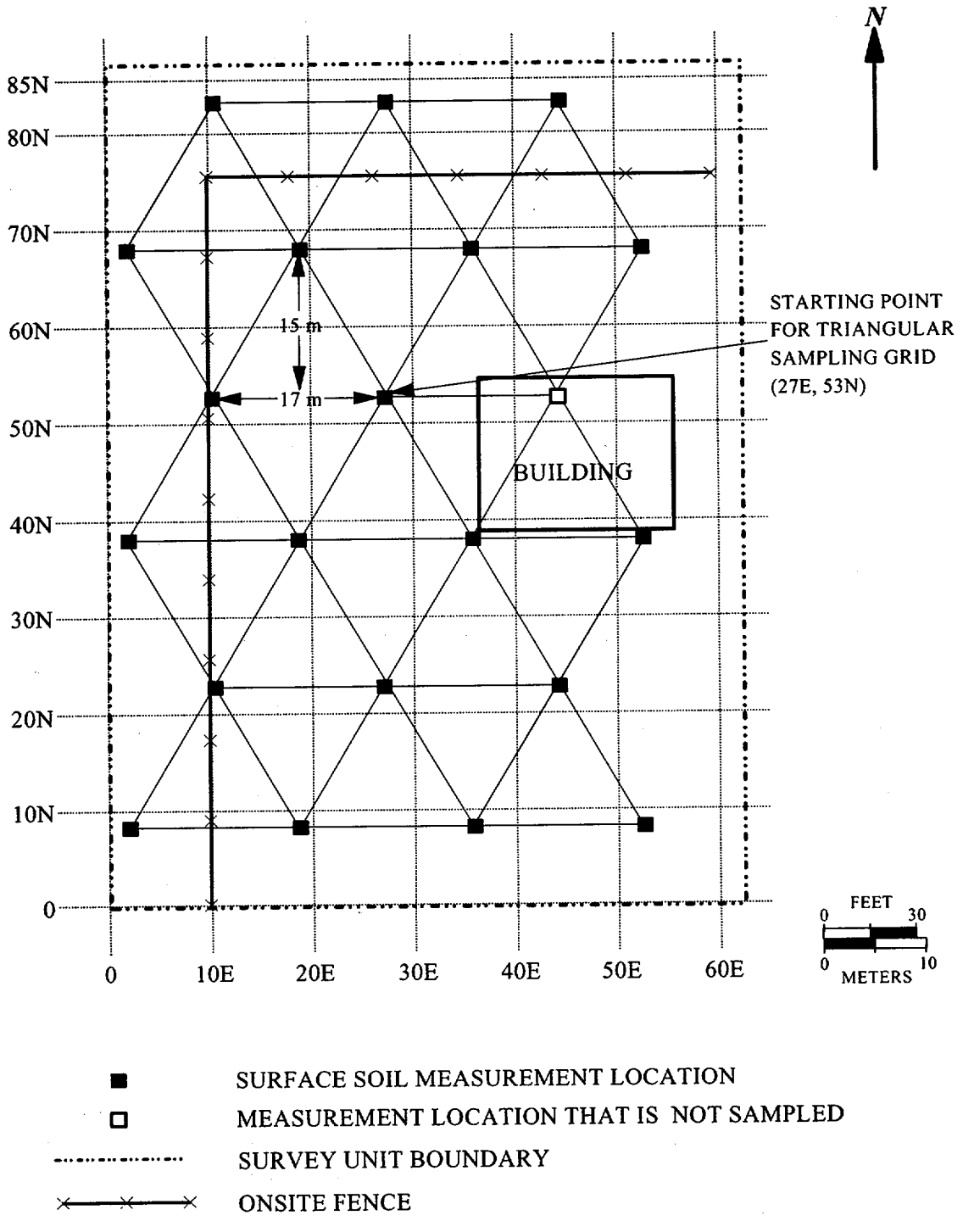


Figure 5.5 Example of a Random-Start Triangular Grid Measurement Pattern

For Class 1 areas a systematic pattern, having dimensions determined in Section 5.5.2.4, is installed on the survey unit. The starting point for this pattern is selected at random, as described above for Class 2 areas. The same process as described above for Class 2 areas applies to Class 1, only the estimated number of samples is different.

Structure Surfaces. All structure surfaces for a specific survey unit are included on a single reference grid system for purposes of identifying survey locations. The same methods as described above for land areas are then used to locate survey points for all classifications of areas.

In addition to the survey locations identified for statistical evaluations and elevated measurement comparisons, data will likely be obtained from judgment locations that are selected due to unusual appearance, location relative to contamination areas, high potential for residual activity, general supplemental information, *etc.* Data points selected based on professional judgment are not included with the data points from the random-start triangular grid for statistical evaluations; instead they are compared individually with the established DCGLs and conditions. Measurement locations selected based on professional judgment violate the assumption of unbiased measurements used to develop the statistical tests described in Chapter 8.

5.5.2.6 Determining Investigation Levels

An important aspect of the final status survey is the design and implementation of investigation levels. Investigation levels are radionuclide-specific levels of radioactivity used to indicate when additional investigations may be necessary. Investigation levels also serve as a quality control check to determine when a measurement process begins to get out of control. For example, a measurement that exceeds the investigation level may indicate that the survey unit has been improperly classified (see Section 4.4) or it may indicate a failing instrument.

When an investigation level is exceeded, the first step is to confirm that the initial measurement/sample actually exceeds the particular investigation level. This may involve taking further measurements to determine that the area and level of the elevated residual radioactivity are such that the resulting dose or risk meets the release criterion.[2] Depending on the results of the investigation actions, the survey unit may require reclassification, remediation, and/or resurvey. Table 5.8 illustrates an example of how investigation levels can be developed.

[2] Rather than, or in addition to, taking further measurements the investigation may involve assessing the adequacy of the exposure pathway model used to obtain the DCGLs and area factors, and the consistency of the results obtained with the Historical Site Assessment and the scoping, characterization and remedial action support surveys.

Table 5.8 Example Final Status Survey Investigation Levels

Survey Unit Classification	Flag Direct Measurement or Sample Result When:	Flag Scanning Measurement Result When:
Class 1	> $DCGL_{EMC}$ or > $DCGL_W$ and > a statistical parameter-based value	> $DCGL_{EMC}$
Class 2	> $DCGL_W$	> $DCGL_W$ or > MDC
Class 3	> fraction of $DCGL_W$	> $DCGL_W$ or > MDC

When determining an investigation level using a statistical-based parameter (*e.g.*, standard deviation) one should consider survey objectives, underlying radionuclide distributions and an understanding of corresponding types (*e.g.*, normal, log normal, non-parametric), descriptors (*e.g.*, standard deviation, mean, median), population stratifications (*i.e.*, are there sub-groups present?), and other prior survey and historical information. For example, a level might be arbitrarily established at the mean + 3s, where s is the standard deviation of the survey unit, assuming a normal distribution. A higher value might be used if locating discrete sources of higher activity was a primary survey objective. By the time the final status survey is conducted, survey units should be defined. Estimates of the mean, variance, and standard deviation of the radionuclide activity levels within the survey units should also be available.

For a Class 1 survey unit, measurements above the $DCGL_W$ are not necessarily unexpected. However, a measurement above the $DCGL_W$ at one of the discrete measurement locations might be considered unusual if it were much higher than all of the other discrete measurements. Thus, any discrete measurement that is both above the $DCGL_W$ and above the statistical-based parameter for the measurements should be investigated further. Any measurement, either at a discrete location or from a scan, that is above the $DCGL_{EMC}$ should be flagged for further investigation.

In Class 2 or Class 3 areas, neither measurements above the $DCGL_W$ nor areas of elevated activity are expected. Any measurement at a discrete location exceeding the $DCGL_W$ in these areas should be flagged for further investigation. Because the survey design for Class 2 and Class 3 survey units is not driven by the EMC, the scanning MDC might exceed the $DCGL_W$. In this case, any indication of residual radioactivity during the scan would warrant further investigation.

The basis for using the $DCGL_{EMC}$ rather than the more conservative criteria for Class 2 and Class 3 areas should be justified in survey planning documents. For example, where there is high uncertainty in the reported scanning MDC, a more conservative criteria would be warranted.

Similarly, DQA for scanning may warrant a more conservative flag, as would greater uncertainty from Historical Site Assessment or other surveys on the size of potential areas of elevated activity. In some cases, it may even be necessary to agree in advance with the regulatory agency responsible for the site on which site-specific investigation will be used if other than those presented in Table 5.8.

Because there is a low expectation for residual radioactivity in a Class 3 area, it may be prudent to investigate any measurement exceeding even a fraction of the $DCGL_W$. The level selected in these situations depends on the site, the radionuclides of concern, and the measurement and scanning methods chosen. This level should be set using the DQO Process during the survey design phase of the Data Life Cycle. In some cases, the user may also wish to follow this procedure for Class 2 and even Class 1 survey units.

5.5.3 Developing an Integrated Survey Strategy

The final step in survey design is to integrate the survey techniques (Chapter 6) with the number of measurements and measurement spacing determined earlier in this chapter. This integration along with the guidance provided in other portions of this manual produce an overall strategy for performing the survey. Table 5.9 provides a summary of the recommended survey coverage for structures and land areas. This survey coverage for different areas is the subject of this section.

Random measurement patterns are used for Class 3 survey units to ensure that the measurements are independent and support the assumptions of the statistical tests. Systematic grids are used for Class 2 survey units because there is an increased probability of small areas of elevated activity. The use of a systematic grid allows the decision maker to draw conclusions about the size of the potential areas of elevated activity based on the area between measurement locations. The random starting point of the grid provides an unbiased method for obtaining measurement locations to be used in the statistical tests. Class 1 survey units have the highest potential for small areas of elevated activity, so the areas between measurement locations are adjusted to ensure that these areas can be detected by scanning techniques.

The objectives of the scanning surveys are different. Scanning is used to identify locations within the survey unit that exceed the investigation level. These locations are marked and receive additional investigations to determine the concentration, area, and extent of the contamination.

For Class 1 areas, scanning surveys are designed to detect small areas of elevated activity that are not detected by the measurements using the systematic pattern. For this reason the measurement locations, and the number of measurements, may need to be adjusted based on the sensitivity of the scanning technique (Section 5.5.2.4). This is also the reason for recommending 100%

Table 5.9 Recommended Survey Coverage for Structures and Land Areas

Area Classification	Structures		Land Areas	
	Surface Scans	Surface Activity Measurements	Surface Scans	Soil Samples
Class 1	100%	Number of data points from statistical tests (Sections 5.5.2.2 and 5.5.2.3); additional measurements may be necessary for small areas of elevated activity (Section 5.5.2.4)	100%	Number of data points from statistical tests (Sections 5.5.2.2 and 5.5.2.3); additional measurements may be necessary for small areas of elevated activity (Section 5.5.2.4)
Class 2	10 to 100% (10 to 50% for upper walls and ceilings) Systematic and Judgmental	Number of data points from statistical tests (Sections 5.5.2.2 and 5.5.2.3)	10 to 100% Systematic and Judgmental	Number of data points from statistical tests (Sections 5.5.2.2 and 5.5.2.3)
Class 3	Judgmental	Number of data points from statistical tests (Sections 5.5.2.2 and 5.5.2.3)	Judgmental	Number of data points from statistical tests (Sections 5.5.2.2 and 5.5.2.3)

coverage for the scanning survey. 100% coverage means that the entire surface area of the survey unit is covered by the field of view of the scanning instrument. If the field of view is two meters wide, the survey instrument can be moved along parallel paths two meters apart to provide 100% coverage. If the field of view of the detector is 5 cm, the parallel paths should be 5 cm apart.

Scanning surveys in Class 2 areas are also primarily performed to find areas of elevated activity not detected by the measurements using the systematic pattern. However, the measurement locations are not adjusted based on sensitivity of the scanning technique and scanning is performed in portions of the survey unit. The level of scanning effort should be proportional to the potential for finding areas of elevated activity based on the conceptual site model developed and refined from Section 3.6.4. A larger portion of the survey unit would be scanned in Class 2 survey units that have residual radioactivity close to the release criterion, but for survey units that are closer to background scanning, a smaller portion of the survey unit may be appropriate. Class 2 survey units have a lower probability for areas of elevated activity than Class 1 survey units, but some portions of the survey unit may have a higher potential than others. Judgmental scanning surveys focus on the portions of the survey unit with the highest probability for areas of

elevated activity. If the entire survey unit has an equal probability for areas of elevated activity, or the judgmental scans don't cover at least 10% of the area, systematic scans along transects of the survey unit or scanning surveys of randomly selected grid blocks are performed.

Class 3 areas have the lowest potential for areas of elevated activity. For this reason, scanning surveys are recommended for areas with the highest potential for contamination (*e.g.*, corners, ditches, drains) based on professional judgment. Such recommendations are typically provided by a health physics professional with radiation survey experience. This provides a qualitative level of confidence that no areas of elevated activity were missed by the random measurements or that there were no errors made in the classification of the area.

The sensitivity for scanning techniques used in Class 2 and Class 3 areas is not tied to the area between measurement locations, as they are in a Class 1 area (see Section 5.5.2.4). The scanning techniques selected should represent the best reasonable effort based on the survey objectives. Structure surfaces are generally scanned for alpha, beta, and gamma emitting radionuclides. Scanning for alpha emitters or low-energy (<100 keV) beta emitters for land area survey units is generally not considered effective because of problems with attenuation and media interferences. If one can reasonably expect to find any residual radioactivity, it is prudent to perform a judgmental scanning survey.

If the equipment and methodology used for scanning is capable of providing data of the same quality as direct measurements (*e.g.*, detection limit, location of measurements, ability to record and document results), then scanning may be used in place of direct measurements. Results should be documented for at least the number of locations estimated for the statistical tests. The same logic can be applied for using direct measurements instead of sampling. In addition, some direct measurement systems may be able to provide scanning data.

As previously discussed, investigation levels are determined and used to indicate when additional investigations may be necessary or when a measurement process begins to get out of control. The results of all investigations should be documented in the final status survey report, including the results of scan surveys that may have potentially identified areas of elevated direct radiation.

5.5.3.1 Structure Surveys

Class 1 Areas. Surface scans are performed over 100% of structure surfaces for radiations which might be emitted from the potential radionuclide contaminants. Locations of direct radiation, distinguishable above background radiation, are identified and evaluated. Results of initial and followup direct measurements and sampling at these locations are recorded and documented in the final status survey report. Measurements of total and removable contamination are performed

at locations identified by scans and at previously determined locations (Section 5.5.2.5). Where gamma emitting radionuclides are present, *in situ* gamma spectroscopy may be used to identify the presence of specific radionuclides or to demonstrate compliance with the release criterion.

Direct measurement or sample investigation levels for Class 1 areas should establish a course of action for individual measurements that approach or exceed the $DCGL_W$. Because measurements above the $DCGL_W$ are not necessarily unexpected in a Class 1 survey unit, additional investigation levels may be established to identify discrete measurements that are much higher than the other measurements. Any discrete measurement that is both above the $DCGL_W$ and exceeds three times the standard deviation (s) of the mean should be investigated further (Section 5.5.2.6). Any measurement (direct measurement, sample, or scan) that exceeds the $DCGL_{EMC}$ should be flagged for further investigation. The results of the investigation and any additional remediation that was performed should be included in the final status survey report. Data are reviewed as described in Section 8.2.2, additional data are collected as necessary, and the final complete data set evaluated as described in Section 8.3 or Section 8.4.

Class 2 Areas. Surface scans are performed over 10 to 100% of structure surfaces. Generally, upper wall surfaces and ceilings should receive surface scans over 10 to 50% of these areas. Locations of scanning survey results above the investigation level are identified and investigated. If small areas of elevated activity are confirmed by this investigation, all or part of the survey unit should be reclassified as Class 1 and the survey strategy for that survey unit redesigned accordingly.

Investigation levels for Class 2 areas should establish a course of action for individual measurements that exceed or approach the $DCGL_w$. The results of the investigation of the positive measurements and basis for reclassifying all or part of the survey unit as Class 1 should be included in the final status survey report. Where gamma emitting radionuclides are contaminants, *in situ* gamma spectroscopy may be used to identify the presence of specific radionuclides or to demonstrate compliance with the release criterion. Data are reviewed as described in Section 8.2.2, additional data are collected as necessary, and the final complete data set evaluated as described in Section 8.3 or Section 8.4.

Class 3 Areas. Scans of Class 3 area surfaces should be performed for all radiations which might be emitted from the potential radionuclide contaminants. MARSSIM recommends that the surface area be scanned. Locations of scanning survey results above the investigation level are identified and evaluated. Measurements of total and removable contamination are performed at the locations identified by the scans and at the randomly selected locations that are chosen in accordance with Section 5.5.2.5. Identification of contamination suggests that the area may be incorrectly classified. If so, a re-evaluation of the Class 3 area classification should be performed and, if appropriate, all or part of the survey unit should be resurveyed as a Class 1 or Class 2 area. In some cases the investigation may include measurements by *in situ* gamma spectroscopy at a

few locations in each structure in a Class 3 area. A gamma spectroscopy system might even be an appropriate substitution for surface scans.

Because there is a low expectation for residual radioactivity in a Class 3 area, it may be prudent to investigate any measurement exceeding even a fraction of the $DCGL_W$. The investigation level selected will depend on the site, the radionuclides of concern, and the measurement and scanning methods chosen. This level should be determined using the DQO Process during survey planning. In some cases, the user may wish to follow this procedure for Class 2 survey units.

The results of the investigation of the measurements that exceed the investigation level and the basis for reclassifying all or part of the survey unit as Class 1 or Class 2 should be included in the final status survey report. The data are tested relative to the preestablished criteria. If additional data are needed, they should be collected and evaluated as part of the entire data set.

5.5.3.2 Land Area Surveys

Class 1 Areas. As with structure surfaces, 100% scanning coverage of Class 1 land areas is recommended. Locations of scanning survey results above the investigation level are identified and evaluated. Results of initial and followup direct measurements and sampling at these locations are recorded. Soil sampling is performed at locations identified by scans and at previously determined locations (Section 5.5.2.5). Where gamma emitting radionuclides are contaminants, *in situ* gamma spectroscopy may be used to confirm the absence of specific radionuclides or to demonstrate compliance.

Direct measurement or sample investigation levels for Class 1 areas should establish a course of action for individual measurements that approach or exceed the $DCGL_W$. Because measurements above the $DCGL_W$ are not necessarily unexpected in a Class 1 survey unit, additional investigation levels may be established to identify discrete measurements that are much higher than the other measurements. Any discrete measurement that is both above the $DCGL_W$ and exceeds three standard deviations above the mean should be investigated further (Section 5.5.2.6). Any measurement (direct measurement, sample, or scan) that exceeds the $DCGL_{EMC}$ should be flagged for further investigation. The results of the investigation and any additional remediation that was performed should be included in the final status survey report. Data are reviewed as described in Section 8.2.2, additional data are collected as necessary, and the final complete data set evaluated as described in Section 8.3 or Section 8.4.

Class 2 Areas. Surface scans are performed over 10 to 100% of open land surfaces. Locations of direct radiation above the scanning survey investigation level are identified and evaluated. If small areas of elevated activity are identified, the survey unit should be reclassified as "Class 1" and the survey strategy for that survey unit redesigned accordingly.

If small areas of elevated activity above DCGL values are not identified, direct measurement or soil sampling is performed at previously determined locations (Section 5.5.2.5). Where gamma emitting radionuclides are contaminants, *in situ* gamma spectroscopy may be used to confirm the absence of specific radionuclides or to demonstrate compliance. Data are reviewed as described in Section 8.2.2, additional data are collected as necessary, and the final complete data set evaluated as described in Section 8.3 or Section 8.4.

Investigation levels for Class 2 areas should establish levels for investigation of individual measurements close to but below the $DCGL_w$. The results of the investigation of the positive measurements and basis for reclassifying all or part of the survey unit as Class 1 should be included in the final status survey report.

Class 3 Areas. Class 3 areas may be uniformly scanned for radiations from the radionuclides of interest, or the scanning may be performed in areas with the greatest potential for residual contamination based on professional judgment and the objectives of the survey. In some cases a combination of these approaches may be the most appropriate. Locations exceeding the scanning survey investigation level are evaluated, and, if the presence of contamination not occurring in background is identified, reevaluation of the classification of contamination potential should be performed.

Investigation levels for Class 3 areas should be established to identify areas of elevated activity that may indicate the presence of residual radioactivity. Scanning survey locations that exceed the investigation level should be flagged for further investigation. The results of the investigation and basis for reclassifying all or part of the survey unit as Class 1 or Class 2 should be included in the final status survey report. The data are tested relative to the preestablished criteria. If additional data are needed, they should be collected and evaluated as part of the entire data set. Soil sampling is performed at randomly selected locations (Section 5.5.2.5); if the contaminant can be measured at DCGL levels by *in situ* techniques, this method may be used to replace or supplement the sampling and laboratory analysis approach. For gamma emitting radionuclides, the above data should be supplemented by several exposure rate and/or *in situ* gamma spectrometry measurements. Survey results are tested for compliance with DCGLs and additional data are collected and tested, as necessary.

5.5.3.3 Other Measurement/Sampling Locations

In addition to the building and land surface areas described above, there are numerous other locations where measurements and/or sampling may be necessary. Examples include items of equipment and furnishings, building fixtures, drains, ducts, and piping. Many of these items or locations have both internal and external surfaces with potential residual radioactivity. Subsurface measurements and/or sampling may also be necessary. Guidance on conducting or evaluating these types of surveys is outside the scope of MARSSIM.

Special situations may be evaluated by judgment sampling and measurements. Data from such surveys should be compared directly with DCGLs developed for the specific situation. Areas of elevated direct radiation identified by surface scans are typically followed by direct measurements or samples. These direct measurements and samples are not included in the nonparametric tests described in this manual, but rather, should be compared directly with DCGLs developed for the specific situation.

Quality control measurements are recommended for all surveys, as described in Section 4.9, Section 6.2, and Section 7.2. Also, some regulatory programs require removable activity measurements (*e.g.*, NRC Regulatory Guide 1.86; NRC 1974). These additional measurements should be considered during survey planning.

5.5.4 Evaluating Survey Results

After data are converted to DCGL units, the process of comparing the results to the DCGLs, conditions, and objectives begins. Individual measurements and sample concentrations are first compared to DCGL levels for evidence of small areas of elevated activity and not to determine if reclassification is necessary. Additional data or additional remediation and resurvey may be necessary. Data are then evaluated using statistical methods to determine if they exceed the release criterion. If the release criterion has been exceeded or if results indicate the need for additional data points, appropriate further actions will be determined by the site management and the responsible regulatory agency. The scope of further actions should be agreed upon and developed as part of the DQO Process before the survey begins (Appendix D). Finally, the results of the survey are compared with the data quality objectives established during the planning phase of the project. Note that Data Quality Objectives may require a report of the semi-quantitative evaluation of removable contamination resulting from the analysis of smears. These results may be used to satisfy regulatory requirements or to evaluate the effectiveness of ALARA procedures. Chapter 8 describes detailed procedures for evaluating survey results.

5.5.5 Documentation

Documentation of the final status survey should provide a complete and unambiguous record of the radiological status of the survey unit, relative to the established DCGLs. In addition, sufficient data and information should be provided to enable an independent re-creation and evaluation at some future time. Much of the information in the final status report will be available from other decommissioning documents; however, to the extent practicable, this report should be a stand-alone document with minimum information incorporated by reference. The report should be independently reviewed (see Section 3.9) and should be approved by a designated person (or persons) who is capable of evaluating all aspects of the report prior to release, publication, or distribution.

EXAMPLE FINAL STATUS SURVEY CHECKLIST

SURVEY PREPARATIONS

_____ Ensure that residual radioactivity limits have been determined for the radionuclides present at the site, typically performed during earlier surveys associated with the decommissioning process.

_____ Identify the radionuclides of concern. Determine whether the radionuclides of concern exist in background. This will determine whether one-sample or two-sample tests are performed to demonstrate compliance. Two-sample tests are performed when radionuclides are present in the natural background; one-sample tests may be performed if the radionuclide is not present in background.

_____ Segregate the site into Class 1, Class 2, and Class 3 areas, based on contamination potential.

_____ Identify survey units.

_____ Select representative reference (background) areas for both indoor and outdoor survey areas. Reference areas are selected from non-impacted areas and

- _____ are free of contamination from site operations,
- _____ exhibit similar physical, chemical, and biological characteristics of the survey area,
- _____ have similar construction, but have no history of radioactive operations.

_____ Select survey instrumentation and survey techniques. Determine MDCs (select instrumentation based on the radionuclides present) and match between instrumentation and DCGLs—the selected instruments should be capable of detecting the contamination at 10-50% of the DCGLs.

_____ Prepare area if necessary—clear and provide access to areas to be surveyed.

_____ Establish reference coordinate systems (as appropriate).

SURVEY DESIGN

_____ Enumerate DQOs: State objective of survey, state the null and alternative hypotheses, specify the acceptable decision error rates (Type I (α) and Type II (β)).

_____ Specify sample collection and analysis procedures.

_____ Determine numbers of data points for statistical tests, depending on whether or not the radionuclide is present in background.

- _____ Specify the number of samples/measurements to be obtained based on the statistical tests.
- _____ Evaluate the power of the statistical tests to determine that the number of samples is appropriate.
- _____ Ensure that the sample size is sufficient for detecting areas of elevated activity.
- _____ Add additional samples/measurements for QC and to allow for possible loss.

_____ Specify sampling locations.

_____ Provide information on survey instrumentation and techniques. The decision to use portable survey instrumentation or *in situ* techniques, and/or a combination of both, depends on whether or not the radiation levels are elevated compared to natural background, and whether or not the residual radioactivity is present at some fraction of background levels.

_____ Specify methods of data reduction and comparison of survey units to reference areas.

_____ Provide quality control procedures and QAPP for ensuring validity of survey data:

- _____ properly calibrated instrumentation,
- _____ necessary replicate, reference and blank measurements,
- _____ comparison of field measurement results to laboratory sample analyses.

_____ Document the survey plan (*e.g.*, QAPP, SOPs, *etc.*)

CONDUCTING SURVEYS

_____ Perform reference (background) area measurements and sampling.

Conduct survey activities:

_____ Perform surface scans of the Class 1, Class 2, and Class 3 areas.

_____ Conduct surface activity measurements and sampling at previously selected sampling locations.

_____ Conduct additional direct measurements and sampling at locations based on professional judgment.

_____ Perform and document any necessary investigation activities, including survey unit reclassification, remediation, and resurvey.

_____ Document measurement and sample locations; provide information on measurement system MDC and measurement errors.

_____ Document any observations, abnormalities, and deviations from the QAPP or SOPs

EVALUATING SURVEY RESULTS

_____ Review DQOs.

_____ Analyze samples.

_____ Perform data reduction on survey results.

_____ Verify assumptions of statistical tests.

_____ Compare survey results with regulatory DCGLs:

_____ Conduct elevated measurement comparison.

_____ Determine area-weighted average, if appropriate.

_____ Conduct WRS or Sign tests.

_____ Prepare final status survey report.

_____ Obtain an independent review of the report.